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LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)

NASA NOAA USDA

LACIE FIELD MEASUREMENTS PROJECT PLAN 1976-77

NASA
National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas 77058

December 1979

LACIE FIELD MEASUREMENTS

Project Plan, 1976-77

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FOREWORD

The LACIE Field Measurements Project was begun in 1974, and data collection was completed after harvest of the 1977 wheat crop. Data were originally distributed to contractor institutions for analyses related to LACIE agricultural remote sensing technology development. Distribution of the data to a broader community of users has already begun, and, in anticipation of continued dissemination and use of the data, the most recent version of the project plan is reproduced here. The LACIE Field Measurements Project Plan for the 1976-77 crop year was prepared in the fall of 1976 and distributed to project participants at that time. The plan should serve equally well now as a reference for new users of the data, as it provides an overview of all phases of the project.

The LACIE Field Measurements Project Plan was formulated with the efforts of many people representing several institutions. The institutions contributing to the plan are

Purdue University/Laboratory for Applications of Remote Sensing
Environmental Research Institute of Michigan
Texas A & M University/Remote Sensing Center
National Aeronautics and Space Administration/Johnson Space Center
United States Department of Agriculture

Investigators are encouraged to obtain further information and to submit requests for field measurements data to

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1. INTRODUCTION

During the past 10 years, much progress has been made in the development of remote sensing technology. Developments in computer-aided analysis techniques applied to multispectral scanner data obtained from satellites for crop inventory have been particularly significant. An assumption underlying these techniques is that different Earth surface features have different spectral reflectance and emittance characteristics and that these differences can be used to identify and describe the features of interest. Broad classes of Earth surface features, such as crop types, soil associations, and forest types, have distinctly different spectral characteristics and have been successfully identified and mapped using Landsat data. However, knowledge of the spectral, spatial, and temporal variations of specific types of Earth surface features is limited. This knowledge is needed to develop the full potential of the multispectral scanner data gathered from space platforms.

Understanding of the relationships between the spectral characteristics and important parameters of Earth surface features can best be obtained by carefully controlled studies over fields and plots where complete data describing the condition of targets are attainable and where frequent, timely spectral measurements can be obtained. To that end, field measurements were begun in support of the Large Area Crop Inventory Experiment (LACIE) (ref. 1). LACIE field measurements data have been acquired in response to requirements generated primarily by the agriculture remote sensing technology development program, and the data have become an integral part of the Supporting Research data base. The role of field measurements in the development and application of remote sensing technology is illustrated in figure 1.

The initial definition of multispectral scanner systems was based on the insight gained through field and laboratory measurements. Later, measurements of the effect of the Southern leaf blight on the multispectral reflectance

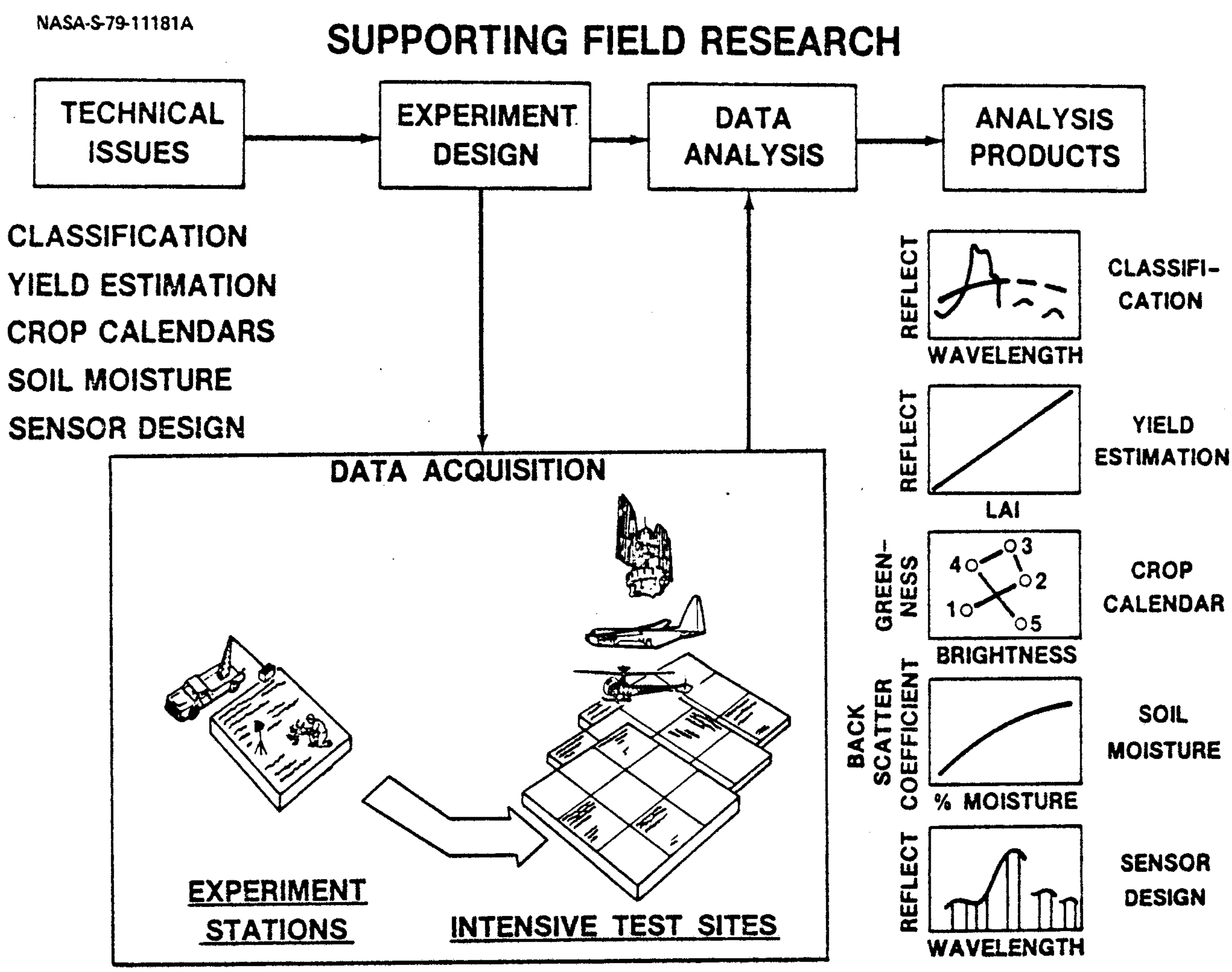

Figure 1.– The role of field measurements in the development and application of remote sensing technology.

and emittance of corn led to the 1971 Corn Blight Watch Experiment, the first quasi-operational demonstration of remote sensing capabilities for agriculture (ref. 2). During this same period, vegetative canopy reflectance and radiative transfer models were being developed and validated with the aid of field measurements data. The availability of these models has led to a broader understanding of the variability in received radiance as measured by a remote sensing system (refs. 3 and 4). These models have also contributed to the development of the "Tasselled Cap" Landsat data transformation (ref. 5). This transformation may help significantly in the accurate identification of wheat, while simultaneously reducing the number of information channels processed. There are many other examples of how and where field measurements data have been used to develop our remote sensing capability. A recent use of data from the current LACIE Field Measurements Project was the simulation and evaluation of thematic mapper data (ref. 6).

The LACIE Field Measurements Project was begun in the fall of 1974 by the NASA Johnson Space Center (JSC). The Laboratory for Applications of Remote Sensing (LARS) at Purdue University has had major responsibility in the technical design and technical coordination of the project. The supporting institutions, particularly the Environmental Research Institute of Michigan (ERIM) and Texas A & M University (TAMU), have provided many valuable recommendations and inputs to the project. This document describes the project plans for the third year of data collection, 1976-77. Although the general implementation of the project remains the same, the plan reflects the advances made during the first 2 years.

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2. OBJECTIVES

The overall objective of the Field Measurements Project is to acquire, process, and distribute to researchers fully annotated and calibrated multitemporal sets of spectral measurements over the wavelength range of 0.4 to 15 μm, along with supporting agronomic and meteorological data. The data base thus created will support investigations into

1. Determining quantitatively the temporal-spectral characteristics of spring and winter wheat, the soil background, and surrounding confusion crops.
2. Defining future multispectral sensor systems.
3. Developing advanced data processing and analysis techniques.

The remote sensing field measurements data set will support a wide range and a large number of LACIE Supporting Research tasks, as well as other investigations (ref. 7). The specific current and planned NASA/JSC research areas that will be supported by field measurements data are described below. The objectives emphasize increasing our understanding of the scene; however, the data may also be used to pursue sensor and data processing objectives.

2.1 SCENE RELATED OBJECTIVES

1. Determination of the spectral separability of wheat, small grains, and other crops as a function of growth stage and by use of multitemporal data.
2. Determination of the effects of crop, soil, and management variables on the spectral properties and spectral identification of wheat over large areas.
3. Determination of the presence, severity, and extent of crop stresses such as drought, disease, and winterkill.
4. Determination of the relation of wheat yield to multitemporal spectral response.

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4. Determination of the relation of wheat yield to multitemporal spectral response.

5. Determination of the year-to-year variation in the condition and spectral response of wheat and other crops.

6. Determination of the effects on the spectral response of geometric factors such as Sun Angle, view angle, and canopy structure of wheat and other selected crops.

7. Determination of the effect of the atmosphere on the measured spectral responses of wheat and other crops.

8. Determination of the characteristics and value of thermal measurements for discrimination of wheat from other crops.

9. Validation of canopy reflectance models.

2.2 SENSOR SYSTEM RELATED OBJECTIVES

The determination of optimum or required multispectral sensor system parameters including spectral bands, signal-to-noise ratio (S/N), noise-equivalent difference in reflectance (NE$\Delta\rho$) and noise-equivalent difference in temperature (NEΔT),* spatial resolution, and time and frequency of sensor overpass.

2.3 DATA PROCESSING SYSTEM RELATED OBJECTIVES

The development of advanced data processing and analysis techniques that utilize multitemporal, spatial, spectral, transformed spectral, and ancillary data characteristics.

*NE$\Delta\rho$ and NEΔT are measures of minimum detectable differences in scene reflectance and temperature.

3. EXPERIMENTAL APPROACH AND RATIONALE

Three important elements of the LACIE Field Measurements Project are (1) that data acquisition is planned and reviewed by data users (LACIE Field Measurements advisory team, sec. 12), (2) that spectral data are supported by extensive ground measurements made by trained and experienced observers, and (3) that spectral data are calibrated, so that data may be compared from site to site, from date to date, and from one sensor to another.

Spectral, agronomic, and meteorological measurements will continue to be made at three LACIE intensive test sites (ITS) during the 1976-77 crop year. The sites are in Finney County, Kansas; Williams County, North Dakota; and Hand County, South Dakota (fig. 2). Finney and Williams were chosen to represent winter and spring wheat growing areas, respectively; Hand County is typical of the transitional zone between winter and spring wheat growing areas. It is important to continue to collect data over these sites for several years to obtain measurements of the year-to-year variation in growing conditions and their influence on spectral response.

The primary sensors to be used are the Purdue/LARS (Exotech 20C) and NASA/JSC (FSAS) truck-mounted spectrometers, the NASA/JSC helicopter-borne field spectrometer system (FSS) and airborne modular multiband scanner (MMS), and the Landsat 2 multispectral scanner (MSS). Each sensor system has unique capabilities for acquiring the necessary data. The spectrometers produce the highest-quality reflectance measurements but provide only limited measurements of spatial variability. On the other hand, the 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. Relative to the Landsat system, 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. Landsat, of course, provides wide-area coverage but is limited in spatial resolution and the placement and number of spectral bands.

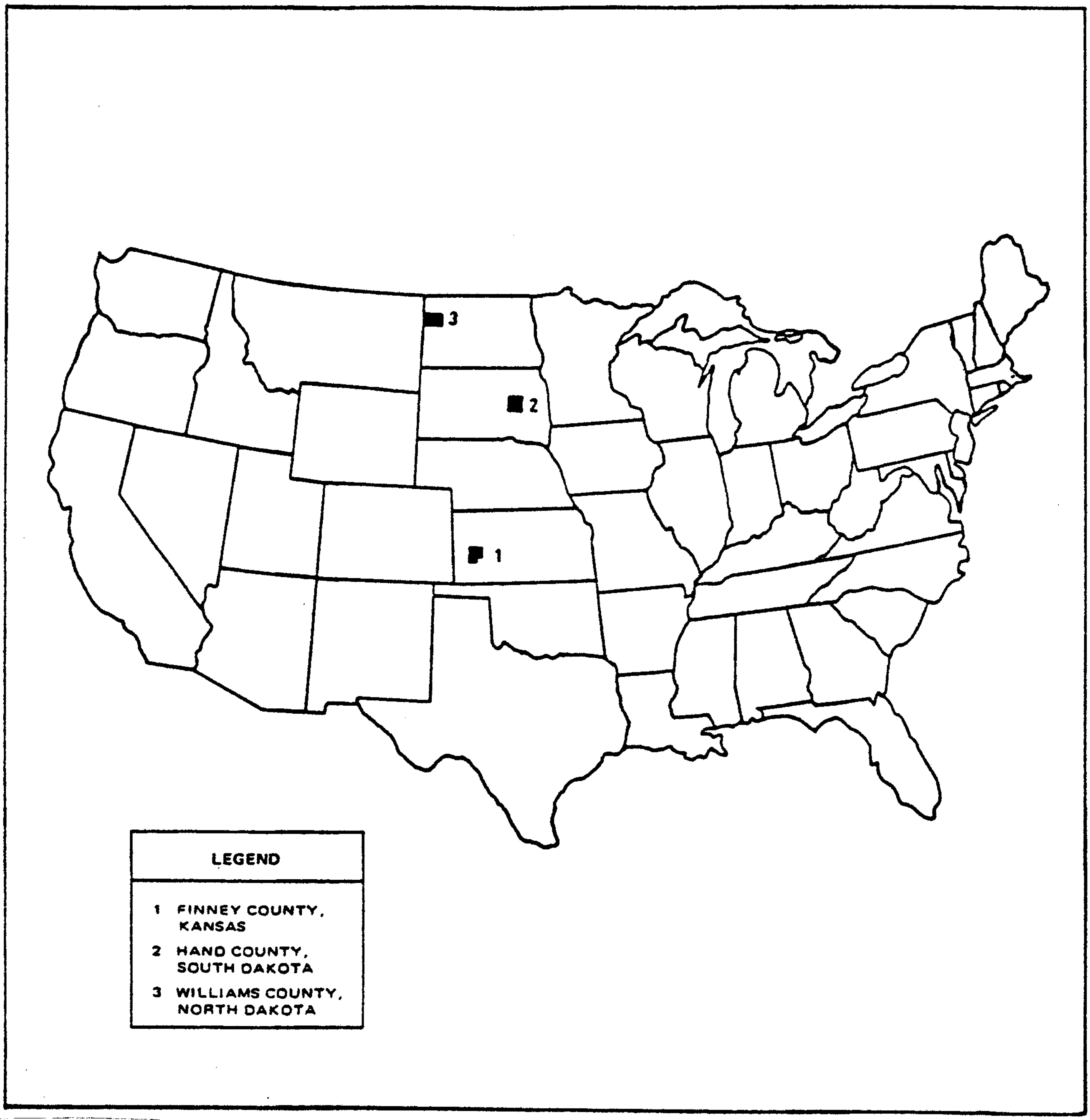

Figure 2.— Locations of test sites for the Field Measurements Project.

LACIE field measurements data acquisition is diagramed in figure 3. The most detailed measurements are made at the experiment stations; progressively less detailed measurements are made over progressively larger areas up to the full 5 x 6 nmi intensive test sites.

The truck-mounted spectrometers collect spectra of crops in controlled experimental test plots 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 are made at the experiment stations, will enable more complete 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 the exact causes of observed differences in spectral response. By having data from plots where only two to four factors are varied under controlled conditions, it is possible to determine more exactly and understand more fully the energy-matter interactions occurring in crops.

FSS and aircraft scanner data are collected in a series of flightlines over commercial fields in the three LACIE intensive test sites. Landsat data include each test site, as well as the area surrounding it. These data provide a measure of the natural variation in the temporal-spectral characteristics of wheat and surrounding cover types.

The spectral measurements are supported by descriptions of the targets and their condition. The descriptive observations, counts, and measurements of the crop canopy include uniformity, maturity, plant height, biomass, leaf area index, percent ground 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. These data are supplemented by aerial photography and ground-level vertical and oblique photographs of the fields and test plots.

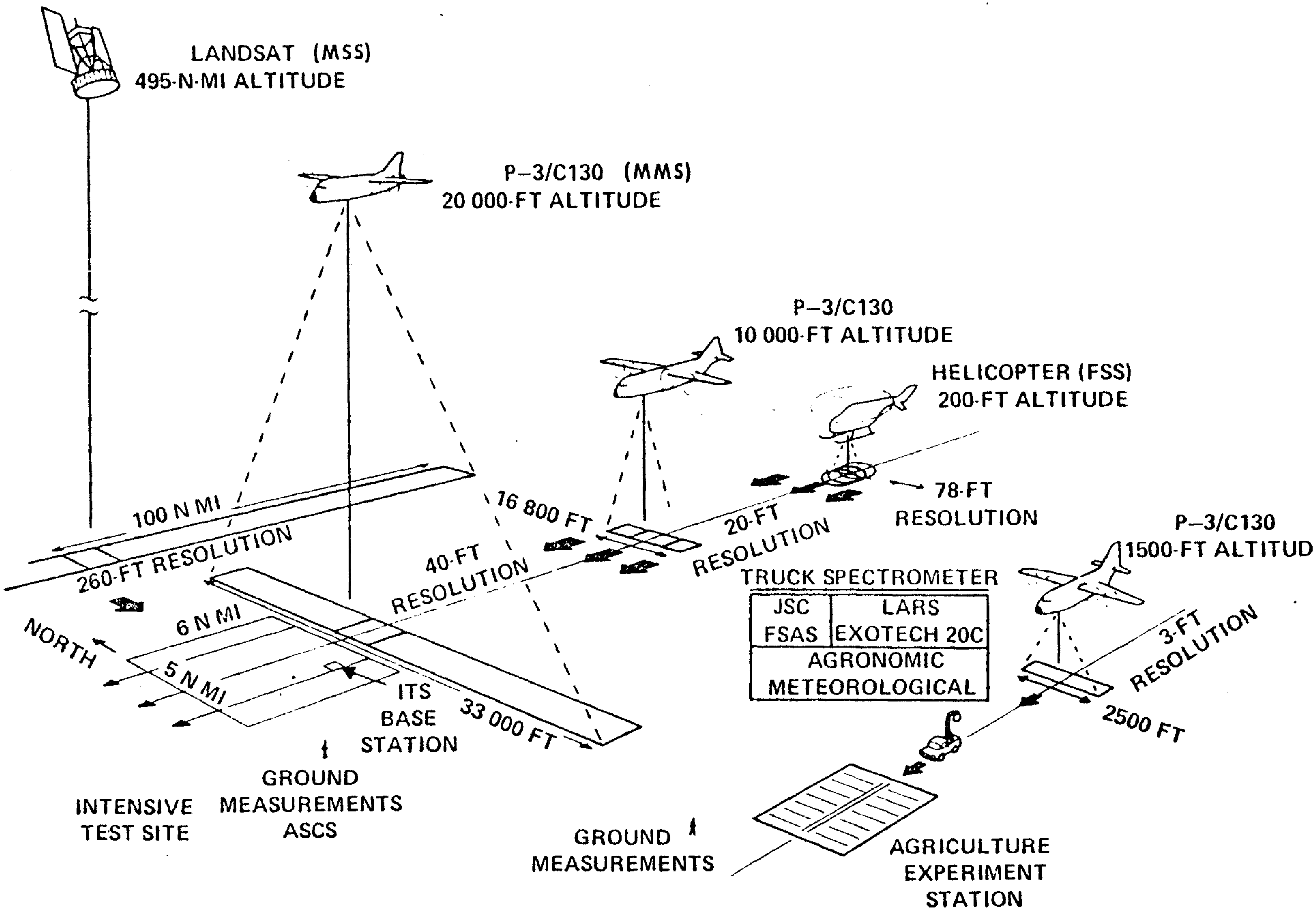

Figure 3.— LACIE field measurements data acquisition.

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The data being acquired are, without question, the most complete agricultural remote sensing data set available in terms of kinds of data, number of fields observed, and frequency of observation. As a result, analyses that were previously impossible can now be carried out.

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.

This year increased emphasis is being placed on data quality evaluation and verification. Timely, quantitative assessment of data quality has two purposes: (1) identification of procedural deficiencies and sensor or processing malfunctions and (2) aid to analysts in selecting data and in interpreting results.

The analyses of the data to accomplish NASA/JSC-sponsored objectives are being performed by Purdue/LARS, ERIM, and TAMU as part of their Supporting Research tasks. The data collection and processing have been planned to meet the data requirements for these tasks. Additional analyses may be performed by investigators at other NASA centers.

4. TEST SITE AND EXPERIMENT DESCRIPTIONS

The test sites are located in Finney County, Kansas; Williams County, North Dakota; and Hand County, South Dakota (fig. 2). Each site consists of a LACIE intensive test site and, in Kansas and North Dakota, an agricultural research station. 1977 will be the third year of LACIE field measurements at the North Dakota site and the second at the Kansas and South Dakota sites. (The first year, field measurements in Kansas were at a different LACIE intensive test site in Finney County.)

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 United States Department of Agriculture/Agricultural Stabilization and Conservation Service (USDA/ASCS) collect the required intensive test site ground data in each county.

4.1 INTENSIVE TEST SITES

The intensive test sites are 5 x 6 nmi in size. Three flightlines, each 6 mi long, are located across each site. The number of fields of each major cover type in each site for 1975-76 is listed in table I.

4.1.1 Finney County, Kansas

The test site is located in the High Plains Tableland physiographic area at 38° 10' N latitude and 100° 3' W longitude. The elevation of the site is about 900 m. The top 3 to 10 m is loess from the early Wisconsin age.

The soils of the test site are in the Mollisol order, Ustoll suborder, and Argiustolls great group. Mollisols are soils that have nearly black, friable, organic-rich surface horizons high in bases. Ustolls are formed in semiarid regions; they are dry for long periods and have subsurface accumulations of carbonates. The major soil series in the area are Richfield and Ulysses,

TABLE I.— NUMBER OF FIELDS OF EACH CROP OR COVER TYPE IN THE TEST SITES, 1976

Cover type	Test site		
	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

which are deep, fertile, well-drained, nearly level to gently sloping, loamy soils of the upland that are well suited to cultivation.

The area has a distint continental type of climate characterized by abundant sunshine and constant wind. The growth cycle of winter wheat is well matched to the available moisture supply. Average annual precipitation for Finney County is 48.5 cm -- 14.3 cm from March through May, 20.1 cm from June through August, 9.7 cm from September through November, and 4.4 cm from December through February.

The major crops in Finney County (table I) are winter wheat, alfalfa, grain sorghum, and corn. The majority of wheat is produced following summer fallowing, 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.

4.1.2 Williams County, North Dakota

The test site is located at 48° 19' N latitude and 103° 21' W longitude. It is representative of the cool, semiarid areas of the northern Great Plains where annual precipitation averages 33 to 38 cm. The site is at an elevation of 650 m and lies in the glaciated area with a drift mantle and an undulating to steep surface.

The soils of the site are in the Mollisol order, Borroll 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 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, wide diurnal ranges in temperature, frequent strong winds, and limited, as well as uncertain and highly variable, precipitation. Average amounts of precipitation are 4.6 cm in the winter, 15.5 cm in the spring, 12.2 cm in the summer, and 4.3 cm in the fall.

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 with seedbed preparation in late April to early May. Planting is generally-in mid-May; heading occurs in late June to mid-July; and harvest is in mid- to late August.

4.1.3 Hand County, South Dakota

The test site is in the north-central Great Plains at latitude 44° 35' N and longitude 98° 58' W. It is a transition area with the Corn Belt to the east, the spring wheat area to the north, and the winter wheat area 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 underlain by less permeable glacial till.

Hand County has a continental climate. Winters are long and cold, and summers are warm. The normal annual precipitation is 47 cm; typically 33 to 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.

4.2 AGRICULTURE EXPERIMENT STATIONS

Agronomic experiments with wheat and other crops are available for study at the agriculture experiment stations at Garden City, Kansas (operated by Kansas State University), and Williston, North Dakota (operated by North Dakota State University). The experimental plots are planted and maintained specifically for LACIE Field Measurements. The advantages of using these experiments are (1) that considerable amounts of agronomic data describing the treatments and their effects on the growth and development of the crop can be readily obtained, and (2) that sources of differences in spectral response can be more readily determined since only the factors of interest are varied while other factors are held constant. The experiments have been designed to provide a range of growing conditions typical of those found in the intensive test sites. Plots are approximately 4 x 12 m in size at Williston and 3 x 30 m at Garden City, and crops are planted, grown, and harvested using conventional practices and equipment.

Each treatment has two replications to enhance statistical analysis of measurements (analysis of variance). The treatments are described below, and the experimental designs for the two locations are shown in figures 4 and 5.

4.2.1 Garden City, Kansas

Small Grain Experiment

The objective of this experiment is to determine if various small grains can be discriminated from each other on the basis of their spectral reflectance. The experiment includes four winter wheat varieties and one variety each of barley, rye, and triticale.

Dryland/Irrigated Winter Wheat Experiments

The principal objective of these experiments is to characterize crop spectral response as a function of crop maturity and to relate the spectral response to crop variables, such as leaf area index and biomass, and to cultural variables, such as planting date, irrigation, and nitrogen fertilization.

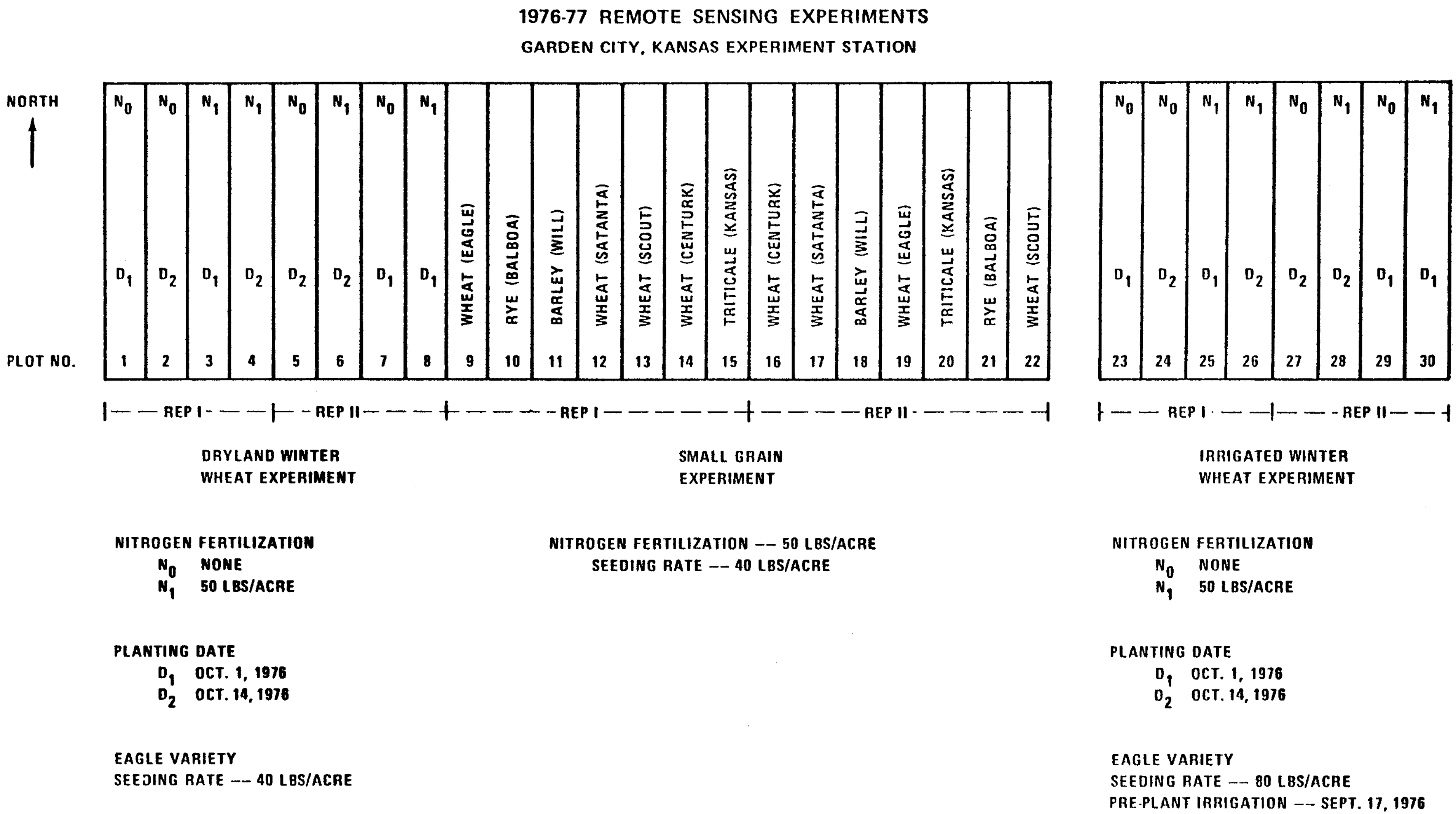

Figure 4.— Remote sensing experiments at the Garden City, Kansas, Agriculture Experiment Station.

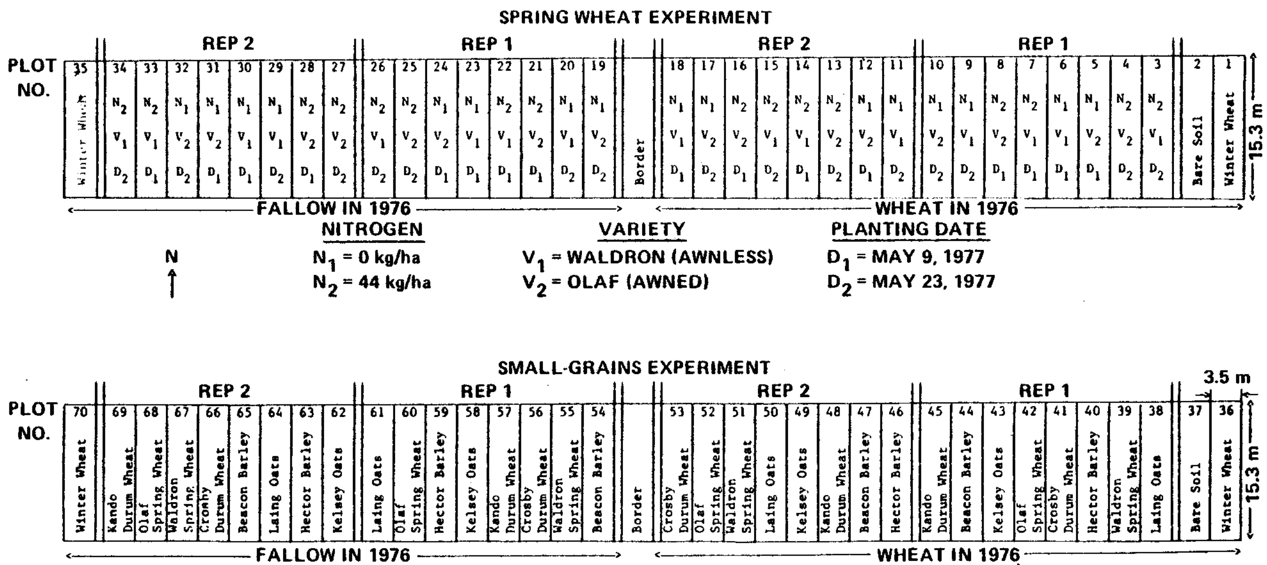

Figure 5.— Remote sensing experiments at the Williston, North Dakota, Agriculture Experiment Station.

Other Crops Experiment

The objective of this experiment is to provide information on the spectral separability of winter wheat and its non-small-grain confusion crops. These crops (test plots omitted from figure 4) include grain sorghum, alfalfa, summer fallow, and pasture.

4.2.2 Williston, North Dakota

Small Grain Experiment

The objective of this experiment is the same as that for the small grain experiment at Garden City. This trial includes winter wheat, spring wheat, durum wheat, oats, and barley.

Spring Wheat Experiment

The objective of this factorial experiment is to quantify the effects on spectral response of the major variables affecting wheat growth, development, and yield. The factors and levels of each factor are

Soil moisture -- fallow in 1976 and wheat in 1976
Variety -- Waldron (awnless) and Olaf (semidwarf, awned)
Planting date -- May 9 and May 23
Nitrogen fertilization -- none and 30 lbs./acre

5. SENSOR DESCRIPTIONS

This section briefly describes the characteristics of the primary sensors being used to acquire spectral data over the intensive test sites and agriculture experiment stations.

The sensors used in the intensive test sites include Landsat 2 MSS, airborne MMS, helicopter-borne S-191 spectrometer (FSS), and tripod-mounted Landsat--band radiometers. The sensor systems acquiring spectral data at the agriculture experiment stations are the truck-mounted spectroradiometer and interferometer systems operated by Purdue/LARS and NASA/JSC, respectively. General descriptions of the sensor systems are given below and summarized in tables II and III. More detailed descriptions of the sensors are available from other references.

5.1 LANDSAT MULTISPECTRAL SCANNER

Landsat 2 MSS data are acquired at 18-day intervals. The MSS data are in four spectral bands from 0.5 to 1.1 μm. The sensor scans crosstrack swaths of 185 km. It has a crosstrack field of view of 11.56° and an instantaneous field of view that subtends a ground area 79 m square. Computer compatible tape (CCT) data and imagery (both color and black-and-white) are acquired for each cloud-free overpass of an intensive test site.

5.2 AIRBORNE MULTISPECTRAL SCANNER

During 1975, the 24-channel scanner was the primary scanner system; during 1976, the modular multiband scanner (MMS) is being used (ref. 8). The MMS, however, does not have any spectral bands in the middle infrared portion (1.4 to 2.6 μm) of the spectrum, which has been shown to be an important region for vegetation analyses.

Nine-inch color and color-infrared photographs are obtained during the scanner flights to be used as reference data by analysts. In addition, 6-band, 70-mm

TABLE II.— CHARACTERISTICS OF THE MULTISPECTRAL SCANNER SYSTEMS

Characteristic	Landsats 1 & 2	MMS	MSS (1975)
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 (deg)	11.56	110	80
Normal operational altitude above ground (km)	994	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 III.— 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, 8.0-14.0	0.4-2.4, 2.8-13.4	0.4-2.5, 3-14	0.5-1.1
Spectral resolution @ 1.0 μm (μm)	0.025	0.025	0.0064	0.3
Scan time (scans/sec)	1	.033-2.0	10	---
Field of view (deg)	22 or 1.25	15 or 0.75	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 (deg)	36	43	46	---
Film type	70-mm color	35-mm color	35-mm color	---

multispectral photographs are acquired over the South Dakota site for the U.S.A./U.S.S.R. remote sensing of vegetation project.

5.3 HELICOPTER-BORNE FIELD SPECTROMETER SYSTEM

The FSS is a filter wheel spectrometer instrument which is a modification of the S-191 sensor used in the Skylab Earth Resources Experiment Package (EREP) (ref. 9). It has been modified by NASA for mounting on a helicopter platform. The instrument produces data in 14-track digital format which are converted to CCT's for subsequent reformating and analysis.

The spectral range of the spectrometer is 0.42-2.50 μm and 8.0-14.0 μm. The field of view is selectable, either 1.25° or 22°. Reflective and emissive data can be collected simultaneously only at the 22° setting, used for all LACIE field measurements data acquisition. At the selected operating altitude of 60 m, spot diameter is 24 m. The helicopter flies at 50 to 55 knots. The boresight camera has a 76-mm focal length and a 36° field of view, giving 40-meter-square ground coverage; it uses 70-mm color film.

5.4 TRUCK-MOUNTED SPECTROMETER SYSTEMS

The Exotech Model 20C field spectroradiometer system operated by Purdue/LARS acquires spectral data over the wavelength region of 0.4 to 15 μm (ref. 10). The instrument features a reflective fore-optic system that permits remote selection of a 0.75° or a 15° field of view. Four circular variable filter wheels are used as the dispersion elements in the spectroradiometer, and a system of four detectors (silicon, lead sulfide, indium antinomide, and mercury cadmium telluride) are used to detect radiation over the wavelengths of interest. The radiation flow from the fore-optic system into the detectors is controlled by two chopper wheels that also serve to expose each detector to appropriate reference sources.

The instrument is equipped with a solar port and diffuser that provides for solar reference in the reflective wavelength region (0.4 to 2.5 μm). The instrument consists of two optical heads that allow coverage of the reflective and emissive wavelength bands separately. 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. 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 that are 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 reformating 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 (ref. 11). 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 carried in an instrumentation van, and the optical head of the instrument is mounted on a mobile aerial tower. The spectral data (expressed as wave number) produced by the instrument are processed by JSC to provide CCT's of spectral reflectance factor.

5.5 LANDSAT-BAND RADIOMETERS

Four-band radiometers (Exotech Model 100) with the same spectral bands as the Landsat MSS are 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.

5.6 METEOROLOGICAL AND ATMOSPHERIC SENSORS

Standard meteorological instrumentation is used to obtain measurements of temperature, barometric pressure, humidity, wind speed and direction, and total irradiance (ref. 12). Solar radiometers are used to obtain measurements of optical depth in seven visible and infrared bands during Landsat overpasses and during aircraft and helicopter missions (ref. 13).

6. SENSOR CALIBRATION AND CORRELATION

A key objective of the LACIE Field Measurements Project is 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 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 only of the scene, whereas scene radiance is a property of the illumination, also. The variation in reflectance, defined as the ratio of the reflected flux to the incident flux, as a function of wavelength, provides the basis for remote sensing and classification of scenes. The directional characteristics of the reflection process are very important to remote sensing, as evidenced, for example, by the effects clouds (diffuse rather than collimated radiators), Sun angle, and view angle have on image classification results.

The fundamental property providing the directional reflectance distribution characteristics of a surface is the bidirectional reflectance distribution function. But, since this property is difficult to measure, more common use is made of the bidirectional reflectance factor (BRF, see equation, sec. 8.3.1). The measurements by the LACIE Field Measurements Project are of BRF. For a discussion of the principles and nomenclature of bidirectional reflectance factor measurements, see reference 14.

6.1 CALIBRATION PROCEDURES

The basic procedures followed in reflectance calibration are outlined in figure 6. All spectral reflectance measurements can be related to the known reflectance of a nearly ideal (completely reflecting, perfectly diffusing) surface -- barium sulfate. A detailed report describing calibration and correlation results is in preparation.

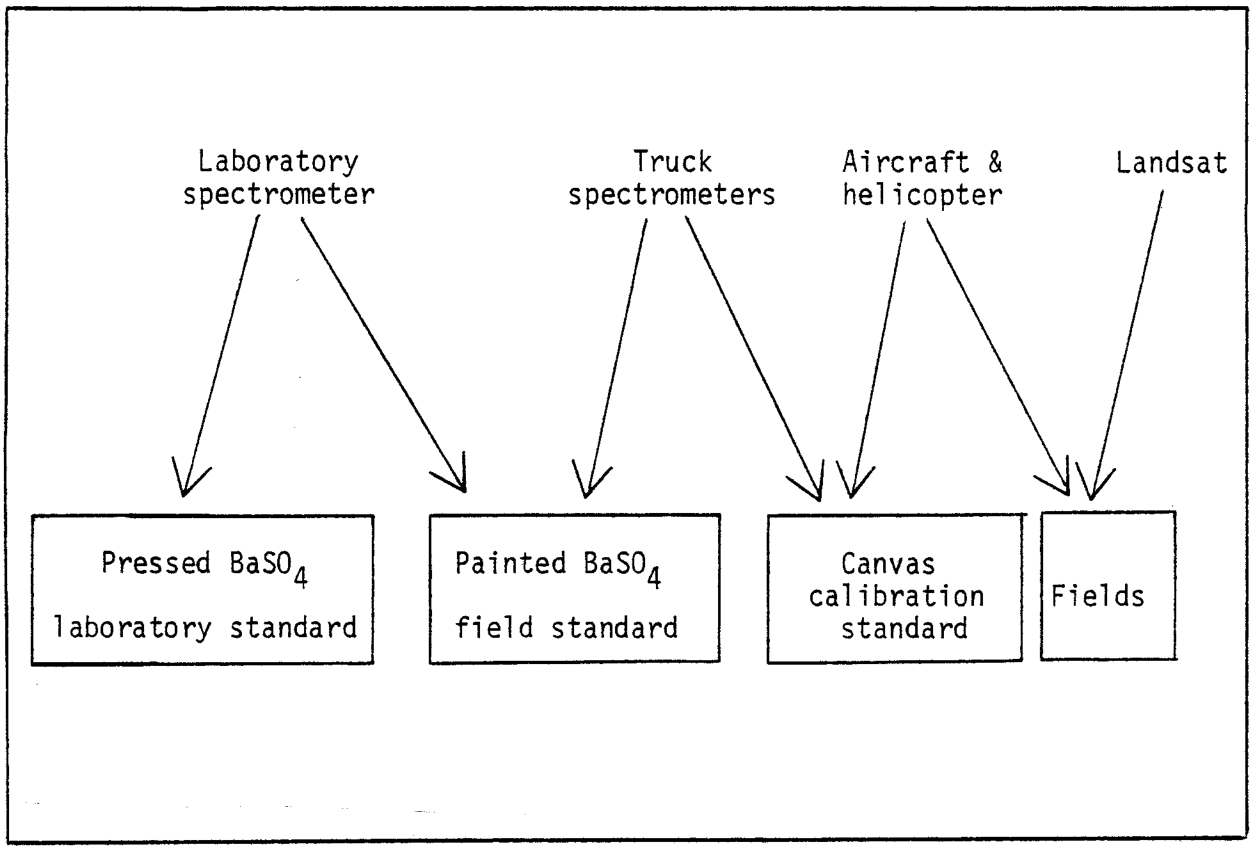

Figure 6.— Schematic of the basic procedures used for reflectance calibration of LACIE field measurements data.

6.1.1 Calibration of Truck-mounted Spectrometer Systems

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

The short-wavelength unit is calibrated for BRF. A standard based on the highly reflecting properties of barium sulfate is used as a basis for the BRF calibration. The standards are prepared according to procedures described by Shai and Schutt (ref. 15).

The painted barium sulfate field standard is used to fill the field of view of the instrument under nearly the same conditions as those for the measurement to be made. 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 BRF with respect to a nearly perfect diffuser. Since it is inconvenient to make this direct comparison for each measurement, the solar port is frequently used to transfer the reflectance standard in the case of 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 BRF of the standard. This procedure produces a BRF for the given Sun angle and normal viewing of the target. See section 8 for the algorithms used.

During the calibration observations, the instrument is aimed straight down at the reflectance standard from a distance of 2.4 m for the Exotech 20C system and 1 m for the FSAS system. Care is taken to ensure that the standards are not shadowed and that the illumination conditions are as similar as possible to the conditions of the observation of the subject. Additionally, steps are taken to minimize the shadowing of skylight and the reflective interactions between the instrument support and the reflectance standard. Calibration observations are made at a frequency commensurate with the efficient operation of each instrument and the acquisition of meaningful data -- at least once every half hour.

Wavelength calibration of the short-wavelength unit is accomplished by irradiating the solar port with sources having known spectral lines. 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.

6.1.2 Calibration of Helicopter-borne Field Spectrometer System

The helicopter-borne spectrometer is calibrated at the site using a 60-percent reflectance canvas panel and the measurements of the canvas panel made by the truck-mounted spectrometer.

To calibrate data from the helicopter FSS, the following data collection sequence is followed:

1. Measure the BRF of the painted barium sulfate field standard with the laboratory spectroradiometer. This is accomplished at the beginning and end of the season in the lab at LARS by comparing the painted barium sulfate panel to pressed barium sulfate.
2. Measure the BRF of the 20 x 40 ft canvas reflectance standard with the truck-mounted spectroradiometer. This is accomplished at the helicopter calibration site by comparing the canvas standard to the painted barium sulfate field standard.
3. Measure the response of the helicopter FSS to the canvas standard. The helicopter FSS makes these measurements just before flying each flightline.
4. Collect data over the flightlines with helicopter FSS.

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

While more elaborate calibration procedures are possible, the interest of the project is in producing data that are directly relatable to satellite data. The radiance received at the satellite includes scene-reflected skylight as well as scene-reflected sunlight. The process of eliminating skylight by subtracting the response of the shadowed scene and shadowed standard has merit in that it produces a quantity related to the reflectance distribution function, which is recognized as a quantity of fundamental utility. However, the additional measurement and calculations add uncertainty to each resultant reflectance number. Furthermore, the reinsertion of modeled, computed, or measured skylight to account for the actual scene radiance adds another measure of uncertainty. Therefore, the single comparison method is used, since, as additional computations accumulate, it is probable that the added uncertainty will be of the same order of magnitude as the skylight itself in the spectral regions of interest.

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 m) and collecting data over the flightlines at 60 m. This procedure assumes that atmospheric absorption and path radiance are negligible for a 60-m path.

The absence of an onboard solar sensor integrated into the instrument makes it desirable that calibrations be performed every 20 minutes. Therefore, the reflectance panels are centrally located and procedures are followed which allow 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 is 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 are converted to spectral radiance using linear interpolation.

6.1.3 Calibration of Airborne Modular Multiband Scanner

The reflective data from the airborne multispectral scanner can be calibrated to BRF using the five gray canvas panels located at the site and the BRF measurements made 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 reflectances and MSS response data collected at low altitude (500 m above the panels) can be related through linear regression. The regression equation can then be used to transform the low-altitude airborne MSS data to scene BRF. Fields overflown at the lower altitude can, in turn, be used as calibration targets to transform higher-altitude data to BRF.

The emissive MMS data are 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.

6.2 CORRELATION PROCEDURES

The three major sensor systems -- the truck-mounted spectrometers, the helicopter-borne spectrometer, and the airborne multispectral scanner -- collect data over the same calibration targets; i.e., the five 20 x 40 ft gray canvas panels. The panels are laid out for each mission at the calibration location at the test site. The helicopter-borne spectrometer measures the BRF of the four darker gray panels during the correlation experiments conducted during each crop year. The data collected by the truck-mounted spectrometers over the five gray canvas panels are used to calibrate the helicopter-borne spectrometer data and the aircraft MMS data. Also, the different truck spectrometers are correlated with each other using the gray canvas panel calibration data. The truck-mounted spectrometers are routinely standardized using painted barium sulfate panels of known reflectance characteristics.*

*The spectrometers were brought together in July 1977 for complete calibration and correlation, including measurement of common targets and reflectance standards, comparison of data collection procedures, and evaluation of instument performance.

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7. DATA ACQUISITION

This section describes the collection of multispectral remote sensing, agronomic, and meteorological data for the intensive test sites and agriculture experiment stations.

Key requirements applying to all forms of data collection are (1) adequate training and briefing of personnel to ensure that data are gathered by uniform, accepted procedures and that agronomic, meteorological, and spectral measurements are coordinated, (2) coordinated data gathering to ensure best use of resources in reacting to weather and other factors affecting the acquisition of useful data, and (3) coordinated data entry into the system to ensure proper registration and calibration.

7.1 DATA ACQUISITION AT 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. The schedule for data acquisition is given in section 12.

7.1.1 Spectral Data Collection

The sensors used are the Landsat MSS, airborne MMS, and helicopter-borne FSS. The data collection procedures are summarized in the following three subsections. Detailed data collection procedures are described in the aircraft project support plans (refs. 16 and 17).

The airborne MMS and helicopter-borne FSS data are collected within a 3- to 5-day mission "window" including or near Landsat 2 overpass day. The data flight is conducted on the first clear day in each window.

Helicopter FSS

The FSS data are to be obtained under stable atmospheric conditions with minimum cloud cover, not to exceed 30 percent. Solar zenith angle is to be greater than 30°.

At the test site, six 6-mile-long flightlines are flown by the helicopter in three sets of two lines. Flightlines are flown at an altitude of 60 m, at 50- to 55-knot ground speed, and in an east-west direction. Approximately 40 to 45 minutes of FSS data are obtained, requiring approximately 1 to 2 hours of helicopter flight time in the test site area. Reference panel calibration measurements from 6 m above the panel are made immediately before flying each set of two flightlines. The reference panel is a 20 x 40 ft specially coated white canvas panel located on a flat platform in the test site.

Airborne Modular Multiband Scanner

The airborne MMS system acquires data over the intensive test sites and agriculture experiment stations concurrently with the helicopter FSS. The intensive test sites are overflown at 3300- and 7000-m altitudes and the experiment stations and calibration panels at 450 m. Collecting data at the two altitudes over the test site provides different spatial resolutions and different amounts of atmosphere between the scene and sensor. Cloud cover is to be less than 30 percent and Sun angle greater than 30°. Five canvas calibration panels (nominal reflectances 6, 12, 18, 30, and 60 percent) are deployed by the ground support team. Nine-inch color-infrared photographs are obtained simultaneously with the scanner data.

Tripod-Mounted Radiometers

A Landsat-band radiometer mounted on a 2-m tripod is used to collect data from one to three fields in the Finney and Williams County test sites. The measurements are made at four times during the day to provide four different Sun angles. A painted barium sulfate field standard is measured between the measurements of the canopy. Spectral measurements include wheat canopy reflectance, soil reflectance, the ratio of diffuse to total irradiance, and leaf transmittance. Canopy description data include leaf area index, biomass, number of tillers and leaves, and photographs. The photographs are vertical and 45° photos, plus plant profile photos. The data are to be acquired at five growth stages (seedling, tillering, jointing, flowering, and mature) at several locations in a typical field.

7.1.2 Agronomic Data Collection

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

Data describing the ITS fields under the flightlines are collected by USDA/ASCS (ref. 18). The following data are collected:

a. Spring and fall inventory of all fields in the test sites (fig. 7)
   - Field number
   - Acreage
   - Crop species and variety
   - Irrigation
   - Fertilization
   - Planting date
   - Other descriptive information

b. Periodic observations coinciding with Landsat overpasses and aircraft/helicopter missions (fig. 8)
   - Field number, acreage, crop identification
   - Growth stage
   - Percent ground cover
   - Plant height
   - Surface moisture condition
   - Weed infestation
   - Field operations
   - Growth/yield detractants
   - Evaluation of stand quality relative to other fields in site
   - 35-mm color photographs
   - Additional descriptive comments

c. Grain yields of selected fields

GROUND TRUTH INVENTORY FORM

TEST SITE # 06 (WILLIAMS, NORTH DAKOTA)
INVENTORY OBSERVATION

DATA RECORDED BETWEEN _ _ / _ _ /76
AND _ _ / _ _ /76

LAND USE CROP CODES

100 SPRING WHEAT (GEN)
101 FORTUNA HRS
102 THATCHER
103 DURUM
104 CHRIS SPRING
1C5 WELLS DURUM
106 LEEDS DURUM
107 JUSTIN SPRING
108 ROLETTE DURUM
109 HERCULES DURUM
110 LARK SPRING
111 BONANZA SPRING
112 WALDRON SPRING
113 RUSHMORE
114 CRIM
115 EMPIRE
116 MANITOU
117 VALLEY
118 CANTHATCH
119 PITIC
120 1809
121 NEEPEWA
122 GLENDEA
123 SELKIRK
124 ERA
125 WASCANA
126 OLAF
200 BARLEY (GEN)
201 LARKER
202 VANGUARD
203 BONANZA
204 DICKSON
205 PRIMUS
206 SHAWBET
207 PIROLINE
208 BETZES
209 STEPTOE
210 FERGUS
211 PARAGON
212 HERTA
213 CONQUEST
214 WISCONSIN
215 HECTOR
216 HYPANA
217 MORAVIAN
300 OATS (GEN)
301 RUSSELL
302 BASIN
303 KELSEY
304 RODNEY
305 LODI
306 KINSEY
307 HARMON
308 MISSION
400 WINTER WHEAT (GEN)
CODE LIST ATTACHED
500 GRASSES/PASTURE ETC.
600 OTHER CROPS (GEN)
601 RAPESEED
602 RYE
603 MUSTARD
604 FLAX (GEN)
605 NORALTA FLAX
606 REDWOOD FLAX
607 CORN
610 BUCKWHEAT
611 SUNFLOWERS
612 DRY BEANS
613 LENTILS
614 DRY PEAS
615 SUGAR BEETS
616 GRAIN SORGHUM
617 SOYBEANS
618 COTTON
700 SUMMER FALLOW
800 NON-AGRICULTURE
900 UNKNOWN CROPS

MAP REFERENCE # OF FIELD	ACREAGE	LAND USE CROP CODE	IRRIGATED	FERTILIZED	PLANTING DATE MONTH DAY YEAR	COMMENTS
0001	11.0	__|__|__	Y N	Y N	_ _ / _ _ / _ _	
0002	13.0	__|__|__	Y N	Y N	_ _ / _ _ / _ _	
0003	18.0	__|__|__	Y N	Y N	_ _ / _ _ / _ _	
0004	18.0	__|__|__	Y N	Y N	_ _ / _ _ / _ _	
0005	19.0	__|__|__	Y N	Y N	_ _ / _ _ / _ _	
0006	38.0	__|__|__	Y N	Y N	_ _ / _ _ / _ _	
0007	40.0	__|__|__	Y N	Y N	_ _ / _ _ / _ _	
0008	19.0	__|__|__	Y N	Y N	_ _ / _ _ / _ _	
0009	4.0	__|__|__	Y N	Y N	_ _ / _ _ / _ _	
0010	34.0	__|__|__	Y N	Y N	_ _ / _ _ / _ _	
0011	19.0	__|__|__	Y N	Y N	_ _ / _ _ / _ _	
0015	44.0	__|__|__	Y N	Y N	_ _ / _ _ / _ _	
0016	15.0	__|__|__	Y N	Y N	_ _ / _ _ / _ _	
0017	27.0	__|__|__	Y N	Y N	_ _ / _ _ / _ _	
0018	37.0	__|__|__	Y N	Y N	_ _ / _ _ / _ _	
0019	27.0	__|__|__	Y N	Y N	_ _ / _ _ / _ _	
0020	17.0	__|__|__	Y N	Y N	_ _ / _ _ / _ _	

Figure 7.— Example ground truth inventory form used by USDA/ASCS.

TEST SITE # 27 (FINNEY, KANSAS)
OBSERVATION 09

GROUND TRUTH PERIODIC OBSERVATION FORM

	MONTH / DAY
LANDSAT PASS DATE	- - / - - /76
OBSERVATION DATE	- - / - - /76

RAINFALL SINCE LAST OBSERVATION _____IN.

LAND USE CODES

100-SPRING WHEAT
200-BARLEY
300-OATS
400-WINTER WHEAT
500-GRASSES/PASTURE
600-OTHER CROPS
601-RAPESEED
602-RYE
604-FLAX
607-CORN
617-SOYBEANS
618-COTTON
700-SUMMER FALLOW
900-UNKNOWN CROPS

GROWTH STAGES

01-NOT PLANTED
02-PLANTED NO EMERGENCE
03-EMERGENCE
04-TILLERING, PREBOOT, PREBUD
05-BOOTED OR BUDDED
06-BEGINNING TO HEAD OR FLOWER
07-FULLY HEADED OR FLOWERED
08-BEGINNING TO RIPEN
09-RIPE MATURE
10-HARVESTED
11-DOES NOT APPLY

GROUND COVER (%)

1- 0- 19
2-20- 39
3-40- 59
4-60- 79
5-80-100

SURFACE MOISTURE CONDITIONS

1-DRY
2-DAMP
3-WET
4-STANDING WATER

WEED GROWTH

1-NEGLIGIBLE
2-SLIGHT
3-MODERATE
4-HEAVY

FIELD OPERATIONS

01-BARE GROUND
02-BARE DISKED/CULTIVATED
03-BARE PLOWED
04-BARESEEDED
05-STANDING STUBBLE
06-STUBBLE DISKED/CULTIVATED
07-STUBBLE PLOWED
08-STUBBLE SEEDED
09-BURNED
10-GRAZED
11-WINDROWED OR SWATHED
12-MOWED OR COMBINED
13-STACKED OR BALED
14-OTHER

GROWTH/YIELD DETRACTANTS

01-SALINITY
02-INSECTS
03-DISEASE
04-DROUGHT
05-MOISTURE
06-WIND
07-HAIL
08-FROST
09-BIRDS
10-POT HOLES
11-UNEVEN STAND
12-WEEDS
13-WINTERKILL
14-LODGING
15-OTHER

STAND QUALITY

1-POOR
2-BELOW AVERAGE
3-AVERAGE
4-ABOVE AVERAGE
5-EXCELLENT
6-DOES NOT APPLY

FIELD NO.	ACREAGE	LAND USE CODE	GROWTH STAGE (CIRCLE ONE)	GROUND COVER (CIRCLE ONE)	PLANT HEIGHT (INCHES)	SURFACE MOISTURE (CIRCLE ONE)	WEED GROWTH (CIRCLE ONE)	FIELD OPERATIONS (CIRCLE ONE)	GROWTH/YIELD DETRACTANTS (CIRCLE ONE)	STAND QUALITY RATING (CIRCLE ONE)	COMMENTS
____	_____	_______	01 02 03 04 05 06 07 08 09 10 11	1 2 3 4 5	[ ][ ][ ]	1 2 3 4	1 2 3 4	01 02 03 04 05 06 07 08 09 10 11 12 13 14	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15	1 2 3 4 5 6	Y N
____	_____	_______	01 02 03 04 05 06 07 08 09 10 11	1 2 3 4 5	[ ][ ][ ]	1 2 3 4	1 2 3 4	01 02 03 04 05 06 07 08 09 10 11 12 13 14	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15	1 2 3 4 5 6	Y N
____	_____	_______	01 02 03 04 05 06 07 08 09 10 11	1 2 3 4 5	[ ][ ][ ]	1 2 3 4	1 2 3 4	01 02 03 04 05 06 07 08 09 10 11 12 13 14	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15	1 2 3 4 5 6	Y N
____	_____	_______	01 02 03 04 05 06 07 08 09 10 11	1 2 3 4 5	[ ][ ][ ]	1 2 3 4	1 2 3 4	01 02 03 04 05 06 07 08 09 10 11 12 13 14	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15	1 2 3 4 5 6	Y N
____	_____	_______	01 02 03 04 05 06 07 08 09 10 11	1 2 3 4 5	[ ][ ][ ]	1 2 3 4	1 2 3 4	01 02 03 04 05 06 07 08 09 10 11 12 13 14	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15	1 2 3 4 5 6	Y N
____	_____	_______	01 02 03 04 05 06 07 08 09 10 11	1 2 3 4 5	[ ][ ][ ]	1 2 3 4	1 2 3 4	01 02 03 04 05 06 07 08 09 10 11 12 13 14	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15	1 2 3 4 5 6	Y N
____	_____	_______	01 02 03 04 05 06 07 08 09 10 11	1 2 3 4 5	[ ][ ][ ]	1 2 3 4	1 2 3 4	01 02 03 04 05 06 07 08 09 10 11 12 13 14	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15	1 2 3 4 5 6	Y N
____	_____	_______	01 02 03 04 05 06 07 08 09 10 11	1 2 3 4 5	[ ][ ][ ]	1 2 3 4	1 2 3 4	01 02 03 04 05 06 07 08 09 10 11 12 13 14	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15	1 2 3 4 5 6	Y N
____	_____	_______	01 02 03 04 05 06 07 08 09 10 11	1 2 3 4 5	[ ][ ][ ]	1 2 3 4	1 2 3 4	01 02 03 04 05 06 07 08 09 10 11 12 13 14	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15	1 2 3 4 5 6	Y N

Figure 8. - Example periodic observation form used by USDA/ASCS.

d. LACIE site assessment reports
   Soils
   Crop production practices
   Climate

7.1.3 Meteorological Data Collection

The following atmospheric and meteorological measurements are made in conjunction with FSS and aircraft scanner data collection at the intensive test sites (ref. 12):

a. Percent cloud cover and type

b. Wet and dry bulb temperature

c. Barometric pressure

d. Total irradiance

e. Wind speed and direction

f. Optical depth at seven visible and near infrared wavelengths

Daily records of air temperature, precipitation, relative humidity, wind, and soil temperature are obtained from the nearest weather station (ref. 19). Also, ASCS personnel make measurements of optical depth at the time of Landsat overpass.

7.2 DATA ACQUISITION AT AGRICULTURE EXPERIMENT STATIONS

This section describes the collection of spectral, agronomic, and meteorological data at the agriculture experiment stations.

7.2.1 Spectral Data Collection

Spectral measurements from agriculture experiment stations are acquired by NASA/JSC at Garden City and Purdue/LARS at Williston. The primary sensors are the Block wideband field interferometer and the Model 20C Exotech field spectroradiometer. These are augmented by Barnes PRT-5 precision radiation thermometers. To obtain data that can be readily compared, the interferometer and spectroradiometer are operated following similar procedures. These instruments are operated from aerial towers at 6 m above the target, a height that minimizes the shadowing of skylight and yet ensures that the field of view of the instrument includes only the desired subject. Care is taken to avoid scene shadowing and minimize the reflective interaction due to personnel or vehicles. The routine data-taking mode in the instruments is straight down. Two measurements of each plot are made by moving the sensor so that a new scene in the plot fills the field of view.

Data recorded at the time of each measurement include 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. A 35-mm color photograph of each observation is taken from the aerial tower. In addition, oblique photos of each plot are taken.

Periodically during the day, spectral measurements of skylight are recorded by the spectrometers having a solar port. To minimize the effect of solar elevation changes on the spectral response, measurements are only made when the Sun angle is greater than 45° above the horizon in the late spring and summer and greater than 30° in the late fall and early spring.

Broadband thermal infrared data are acquired with a PRT-5 radiometer boresighted with the spectrometers.

7.2.2 Agronomic Data Collection

Crop and soil information for the plots at the research stations are collected at Garden City by NASA/JSC with assistance from the agriculture experiment station personnel and at Williston by Purdue/LARS. The following data are collected:

a. Inventory of all plots at beginning of season
   Plot number
   Plot size
   Crop species and variety
   Irrigation practices
   Fertilization history
   Soil type
   Planting date
   Other descriptive information

b. Observations for each plot at time of each mission (fig. 9)
   Field number and crop identification
   Growth stage
   Plant height
   Number of leaves, stems, and heads
   Fresh weight of plants
   Dry weights of leaves, stems, and heads
   Leaf area index
   Surface soil moisture and roughness
   Soil moisture profile
   Evaluation of stand quality
   Stress factors (insect damage, disease, nutrient deficiencies, moisture stress, weeds, or lodging)
   Field operations such as cultivation or harvesting
   Vertical (for determination of percent ground cover) and oblique 35-mm color photographs

c. Grain yields and test weights

SUMMARY OF AGRONOMIC DATA
REMOTE SENSING EXPERIMENTS

MISSION: ____________________

DATE	PLOT NO.	GROWTH STAGE	PLANT HEIGHT (CM)	NO. LEAVES PER STEM	LEAF CONDITION % LEAVES			NO. STEMS	NO. HEADS	WT. FRESH BIOMASS (GRAMS)	WT. DRY BIOMASS (GRAMS)				PLANT MOISTURE (%)	LEAF AREA INDEX	SURFACE SOIL MOISTURE (%)
					GREEN	YELLOW	BROWN				LEAVES	STEMS	HEADS	TOTAL			

Figure 9.— Summary data sheet for recording agronomic data from the agriculture experiment station test plots.

7.2.3 Meteorological Data Collection

The following atmospheric and meteorological measurements are made by NASA/JSC and Purdue/LARS in conjunction with the truck-mounted spectrometer data collection:

a. Percent cloud cover and type

b. Wet and dry bulb temperature

c. Barometric pressure

d. Total irradiance

e. Wind speed and direction

Daily records of air temperature, precipitation, relative humidity, radiation, wind, and soil temperature are obtained from the weather station at each experiment station.

8. DATA PROCESSING

This section describes the data processing and reformating operations performed on the field measurements data.

8.1 LANDSAT MULTISPECTRAL SCANNER DATA

Landsat imagery and CCT's are received at Purdue/LARS via standing orders placed with the NASA Goddard Space Flight Center (GSFC). The data are screened for cloud cover; if the frame is 75-percent or more cloud-free, it is reformated to LARSYS Version 3 format and stored in the computer data library at LARS. Selected scenes of multitemporal data have been registered by NASA/GSFC for LACIE.

8.2 AIRBORNE MULTISPECTRAL SCANNER DATA

Eleven-channel MMS data are recorded on 14-track digital tape onboard the aircraft. The aircraft tapes are reproduced to generate visicorder imagery at JSC. Visicorder imagery is a 13-cm-wide, medium-contrast paper strip record of the tape contents. The imagery is reviewed to determine the start and stop time of each flightline recorded on a particular aircraft tape. The aircraft tapes are reproduced a second time, selecting data from the flightline time intervals only. These data are written onto CCT's in JSC Universal Imagery format. In addition to the tapes, quality control printouts are generated for evaluation. The CCT's are sent to LARS, where they are reformated into LARSYS Version 3 format and stored in the field measurements multispectral scanner data library. The library tapes are then available for analysis by users of the Purdue/LARS computational facility and may be copied for distribution to users outside LARS. Note that MMS data are simply reformated and that relative radiance values are not altered or calibrated in any way during transmittal from the aircraft tape to the Purdue/LARS library. If calibrated (BRF) data, rather than relative response, are required for particular analyses, calibration can be performed utilizing measurements made by the aircraft scanner of the gray-level calibration panels along with those made by the helicopter and truck spectrometers.

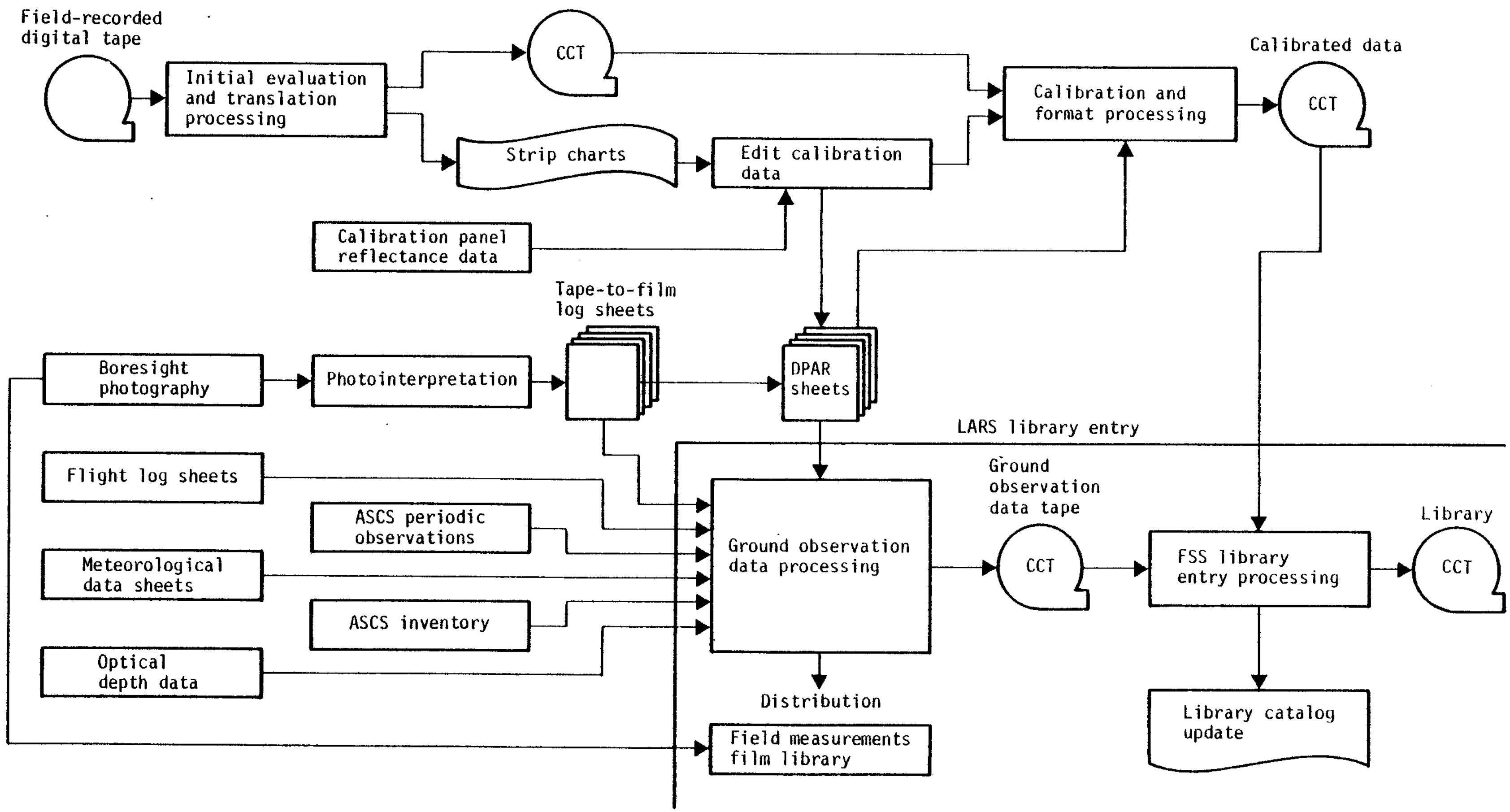

Figure 10.— FSS data processing steps.

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8.3 FIELD SPECTROMETER SYSTEM DATA

FSS data are digitized to 10-bit precision and recorded on 14-track, 1-inch-wide instrumentation tape in digital form onboard the helicopter. Current inventory, periodic observation, and meteorological data corresponding to each field are later added to form a full complement of FSS-associated data. With the exception of the boresight camera photographs and flight log information, this complement of data is computer processed and stored in the Field Measurements Project spectrometer data library for subsequent analysis. Data processing flow for the FSS is shown in figure 10.

8.3.1 Initial Ground Processing

The 14-track digital tapes recorded onboard the helicopter are reproduced at NASA/JSC and converted to CCT format. Also generated are strip charts and other outputs used for data quality evaluation. The strip charts are later edited to delineate scans collected directly over the calibration panel for use in calibrating the field data into BRF. This edit is very critical since the helicopter cannot always hover directly over the calibration panel for a long time. For each calibration run, the contiguous set of panel scans having the highest uniform response on the strip chart is selected. A unique calibration data set is collected and edited for each flightline. During computer processing at JSC, instrument response values are averaged into 61 reflective bands -- in 0.02 μm intervals from 0.40 to 1.10 μm and in 0.05 μm intervals from 1.10 to 2.40 μm. BRF is computed as follows:

$$R = \frac{V_t - b_1}{V_p - b_2} R_p k$$

where R = bidirectional reflectance factor

V_t = instrument response over the target

V_p = instrument response over the calibration panel

b = detector bias values

R_p = BRF of the canvas panel

k = field-of-view conversion constant

Basically, BRF is computed as the ratio of the instrument response over the target to the response over the reflectance standard. To compensate for the standard's being less than a perfect reflector (BRF less than 1.0), R_p is used. The constant k is used to compensate for the change in instrument field of view for the target and calibration panel data. The above calculation is performed for each of 61 wavelength band values.

Emissive data (8 to 14 μm) are averaged into 12 wavelength bands, each 0.5 μm wide. Instrument response values are converted to radiance units by referencing instrument responses to internal calibration sources. See reference 20 for additional details on FSS software operations at JSC.

Boresight photography collected coincidently with spectrometer data is used by photointerpreters to generate tape-to-film data sheets showing the time interval corresponding to the helicopter overpass of each field or object. The time is read from a precision clock mounted within the camera and viewed in each photo frame. The clock is synchronized with the spectrometer time code generator with an error not greater than 2 seconds. The tape-to-film sheets are transcribed to data processing action request (DPAR) sheets with modifications as dictated by data quality evaluations and other inputs. DPAR sheets are subsequently keypunched and input to the calibration and formating processor. Available calibration panel BRF data are supplied from the Purdue/LARS Exotech 20C and NASA/JSC FSAS.

Each spectral scan is calibrated to BRF by referencing the data to the most current (previous) calibration panel scan and the panel BRF values. Processing results are recorded on CCT's. Copies of the CCT's, DPAR sheets, flight logs, meteorological data, optical depth data, tape-to-film logs, and photographs are sent to LARS for further processing.

8.3.2 Final Processing

At LARS, run numbers are assigned and stamped on the tape-to-film log sheets. A run number is assigned to all time intervals corresponding to a single target or field. Only time intervals included on the DPAR forms (and thus processed) are considered. Tape-to-film, meteorological, optical depth, and ASCS data sheets are keypunched and processed by the ground observation data processor to produce a ground observation data tape for each time interval or field for which FSS data have been processed at JSC. This record contains all the information about a given field which can be found on the several data sheets.

Finally, the JSC spectral data and ground observation data tapes are combined with program control data to produce the FSS Field Measurements Project library tape. During this final processing step, the scans of single fields (and times) are averaged to form a single scan of spectra. Statistical analysis algorithms are used to omit atypical scans during the averaging process. Also during this step, the data may be recalibrated if updated calibration panel BRF values become available. Recalibration is performed as follows:

$$R_u = R \frac{R_n}{R_o} \text{ for each wavelength}$$

where R_u = updated BRF (percent)

R = BRF from JSC-processed data tape

R_n = updated BRF for the canvas panel

R_o = BRF for canvas panel used during JSC processing

8.4 EXOTECH MODEL 20C SPECTRORADIOMETER DATA

Field spectroradiometer data acquired by Purdue/LARS are collected by the Exotech Model 20C and PRT-5 field instrumentation systems. Procedures for handling and processing data collected by these systems are outlined in this section. The general flow of data through the processing system is shown in figure 11.

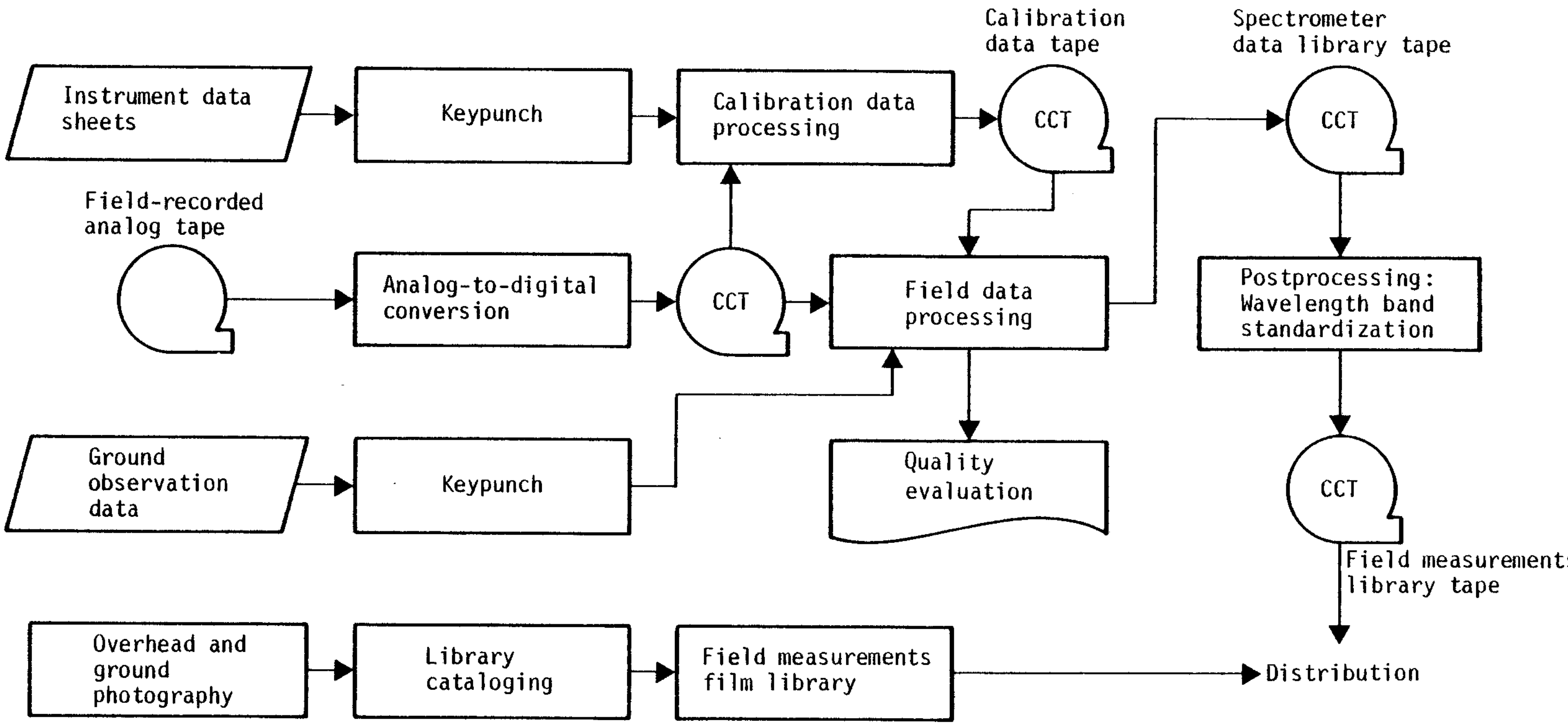

Figure 11.— LARS field spectroradiometer data processing steps.

During field operations, instrument parameters are recorded on measurement record sheets and later they are edited in the laboratory. The edited forms are keypunched and used in the preprocessing and processing steps discussed below. Spectral data from the 20C spectroradiometer are recorded on seven-track analog magnetic tape. At the LARS laboratory, the field-recorded tapes are reproduced and digitized to 10-bit precision. The digital data are stored on a CCT and later displayed for data quality evaluation, at which time spurious spectra are designated for deletion from later processing steps. As shown in figure 11, the original CCT is used in the preprocessing and final processing steps.

In the preprocessing step, calibration data are selected from the original CCT and processed to produce a CCT containing reduced calibration data. The calibration data tape is later used in final processing for calibrating field spectrometer data into BRF. Agronomic and soils data collected in the field are recorded on LARS ground observation sheets. In the laboratory, the sheets are completed under supervision of a project agronomist. Information not available at the time of field data collection is added to the sheets. The added information includes leaf area index, plant moisture content, and the catalog numbers of photographs taken during the mission. The completed forms are then keypunched for computer input.

In the final processing step, field data from the original CCT, data from the calibration tape, and ground observation data are combined to produce the spectrometer data library tape. This processing step also produces data quality tabulations that are evaluated and may result in subsequent reprocessing of parts of the data. The spectrometer library tape contains the full-resolution form of the Exotech 20C data and must subsequently be postprocessed into the specialized storage format for the Field Measurements Project. In this step, wavelength bandwidths are standardized to 0.01 μm for reflective bands and 0.05 μm for emissive bands, as prescribed by the Field Measurements Project spectrometer tape format. The resultant CCT is stored in the field measurements digital tape library and is distributed to project analysts.

BRF calibration is achieved as follows (for each wavelength):

$$R_s = \frac{V_s}{V_b} R_b$$

where R_s = BRF of field calibration standard (measured in laboratory)

V_s = instrument response for field standard

V_b = instrument response for pressed $BaSO_4$ reflectance reference

R_b = BRF of pressed $BaSO_4$ (published table)

$$R_t = \frac{V_t}{V_i} \frac{V_i'}{V_s} R_s$$

where R_t = BRF of scene (measured in field)

V_t = instrument response for scene

V_i = instrument response to solar port at time V_t measured

V_i' = instrument response to solar port at time V_s measured

V_s = instrument response for field standard

8.5 FIELD SIGNATURE ACQUISITION SYSTEM DATA

The FSAS is a NASA/JSC truck-mounted visible-infrared interferometer that produces interferograms sampled 1024 times per scan, where one sample is taken for every 30.865 wave numbers. During field operations, interferograms are digitized by a 12-bit analog-to-digital converter, Fourier-transformed into spectra, and stored on a magnetic tape by the NOVA 1200 computer. The data are calibrated to BRF and radiance units at a JSC laboratory. Detailed ground observations are appended to the spectra and the data are sent to LARS for distribution and storage in the field measurements data library. Figure 12 illustrates the basic data processing flow for the FSAS.

Field-recorded digital data tapes are delivered to a JSC laboratory for processing. The data are processed in three phases: UNIVAC conversion, ratioing, and calibration. In phase one, the nine-track field-recorded data tapes are

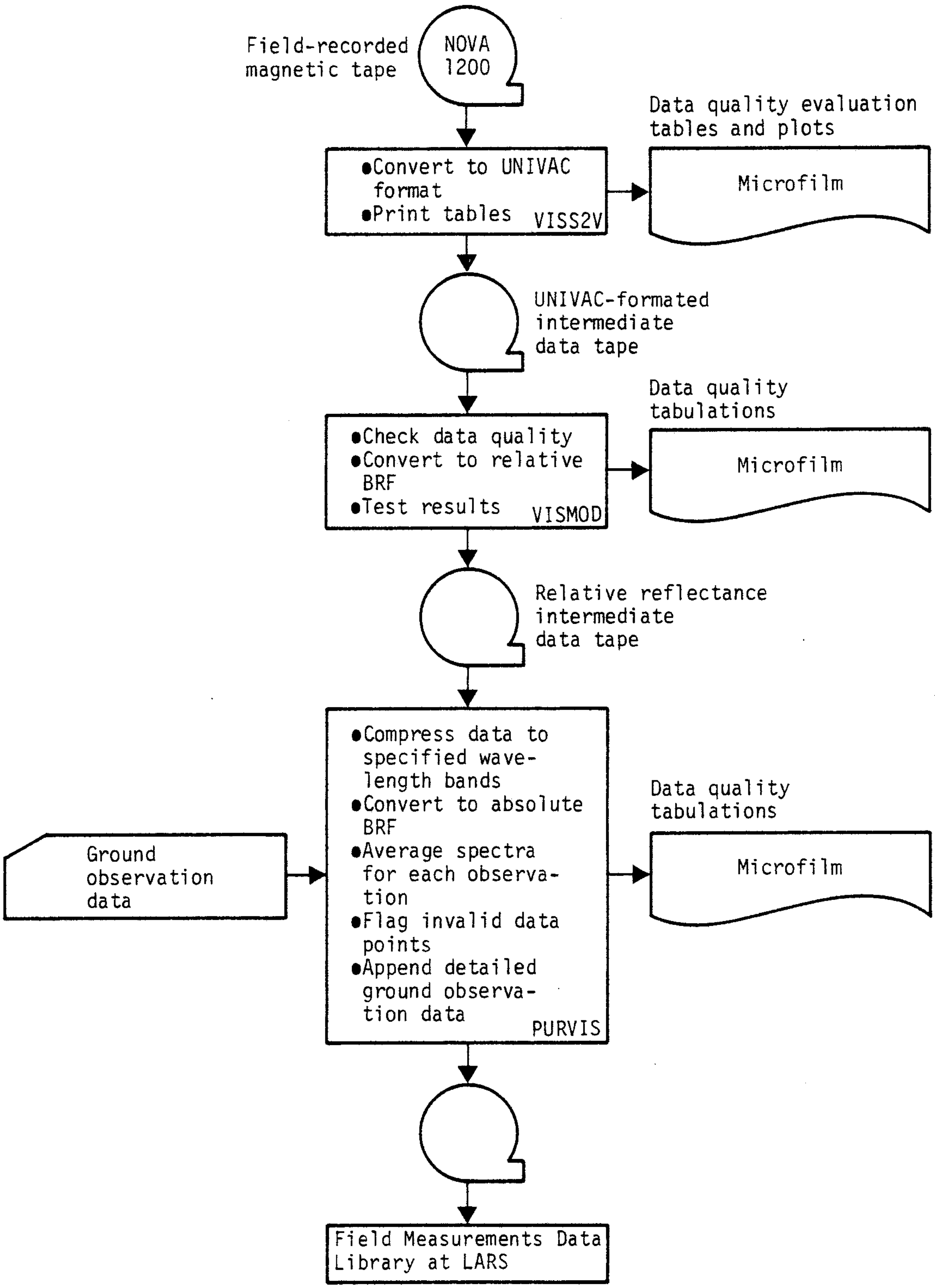

Figure 12.— FSAS data processing steps.

read by the UNIVAC 1108 and converted to UNIVAC format. Optionally, this phase will produce data quality tabulations and plots on microfilm for data evaluation purposes.

In phase two, the UNIVAC-formated tape is read with control data to produce relative reflectance ratios. Each target spectrum is ratioed with its respective reference standard spectrum to produce a relative reflectance spectrum. A test is used to ensure that no ratio will approach infinity. If the test indicates the ratio will be too large, as in atmospheric absorption bands, the ratio is set to zero. Phase-two processing produces data quality tabulations and relative reflectance intermediate data tape.

In phase-three processing, the relative reflectance data tape and ground observation data decks are combined to generate the final data product. Data points are averaged into 0.01-μm wavelength bands (0.05-μm for emissive data) as prescribed for the field measurements data library. Relative reflectance values are converted to BRF by applying reference standard BRF values. Sequentially collected spectra over a single target are then averaged to form a single spectrum for each target observation. Data points with large deviations from neighboring points are flagged for manual evaluation and possible deletion. Detailed ground observation data corresponding to each averaged spectrum are read from card decks to formulate a header record. Header data and calibrated spectra are written on magnetic tape for delivery to LARS and subsequent entry into the field measurements data library. Phase-three processing also produces tabular output on microfilm.

Data tapes are received at LARS and copied into the field measurements data library. FSAS data are stored in the LARS spectrometer data format in the online field measurements computer library. The data may be accessed by anyone utilizing the LARS computational facility.

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9. DATA EVALUATION AND VERIFICATION

An important requirement in the Field Measurements Project is that the quality of data be monitored and documented in a timely fashion. The purpose of this is twofold: First, data verification can flag inadequate procedures or poor sensor performance, which can then be corrected for subsequent missions. Second, the data evaluation documents and results can aid analysts in the selection of data and the interpretation of results.

To verify data adequately, information needs to be collected on three major phases: (1) field procedures, including instrument comparisons and system tests; (2) instrument checks, including prefield, field, and postfield checks; and (3) data evaluation. A summary of the key steps in data evaluation and verification follows:

Landsat MSS data
- Estimate cloud cover over test site.
- Estimate cloud cover over entire frame.

Airborne MMS and photographic data
- Monitor scanner system performance and total irradiance charts during data acquisition.
- Review MMS imagery.
- Review MMS histograms.
- Review photography.

Helicopter and truck-mounted spectrometer system data
- Test preseason spectrometer performance.
- Monitor system performance during mission.
- Review spectrometer strip charts for each mission.
- Review and annotate film.
- Study processing quality control reports.
- Review total irradiance charts collected during data acquisition.
- Review data acquisition procedures periodically.
- Review processed data (spectral, agronomic, and meteorological).
- Study calibration panel data.
- Study correlation of spectrometers using gray panel and color panel data.

Solar radiometer data (optical depth)

Calibrate instruments to international standards (independent institution).

Review data for each mission carefully.

Test sensor periodically, including filter bandpasses.

Compare data from channel to channel, day to day.

9.1 LANDSAT MULTISPECTRAL SCANNER DATA

The Landsat data is reviewed to verify that the test site is included. Also, the cloud cover for both the test site and the frame are noted. Only the frames having 50-percent or better cloud-free coverage of the test site are processed into LARSYS format for use by researchers. Channels with poor data quality are noted in the LACIE Field Measurements Data Library catalogs.

9.2 AIRBORNE MULTISPECTRAL SCANNER AND PHOTOGRAPHIC DATA

Variability in illumination of the flightline during data collection caused by clouds over or near the flightline seriously reduces the relative accuracy of the data and greatly complicates the analysis of the data. Data are to be collected only when conditions have been stable for at least 15 minutes. To determine whether conditions are suitable for data collectiion, a strip chart recording of total incidence pyranometer data is acquired during data acquisition periods at the calibration site. The strip chart is used after the mission by data analysts to determine actual conditions under which data were collected. This procedure was implemented early in 1976.

After the mission, both qualitative and quantitative checks of data quality are made. The qualitative checks include examination of the total incidence pyranometer data and examination of imagery and histograms of each spectral band. Examination of the imagery can be used to verify that the flightline was properly flown, to detect clouds and cloud shadows, and to discover gross problems in sensor performance, such as banding. These checks are performed at JSC; any abnormalities are noted in a data quality report for each mission.

9.3 HELICOPTER-BORNE AND TRUCK-MOUNTED SPECTROMETER DATA

Major factors contributing to the uncertainty in the helicopter-borne and truck-mounted spectrometer data are, in order of importance, clouds, calibration procedures, atmospheric conditions, instrument performance, and data processing system performance. The strip chart pyranometer records the cloud and atmospheric conditions during the mission. The requirement for sensor performance evaluation has long been recognized and quick-look tests, as well as more extensive instrument tests, are currently performed. Preseason tests are performed for each instrument by the institutions that operate them. The preseason tests include wavelength calibration, field-of-view alignment, and instrument linearity studies.

On a clear day, the most critical factor in system uncertainty is the instrument alignment during the calibration process. It is most important that the field of view of the instrument be filled by the calibration panel. Alignment of the fields of view of the FSS, Exotech, and FSAS should be checked regularly. A procedure for assessing system uncertainty which also provides an indication of alignment has been developed and is used by Purdue/LARS. It consists of applying a cosine correction for solar zenith angle changes to the calibration panel measurements. All calibration spectra should be approximately the same after cosine correction. If significant deviations are noted, attempts are made to determine their cause.

System performance at various spectral reflectance levels is studied. This information is used to evaluate the performance of the circular variable filter wheel. Periodically, the helicopter and truck systems take data over the gray panels used to calibrate the MMS. The processed spectra are examined for repeatability from mission to mission and the smoothness of the transition from one filter to the next. Malfunctions of the instrument are evidenced by gross changes from mission to mission of the gray panel spectra. Any systematic offset in the spectra at the transition from one filter section to another indicates an instrument malfunction. Also, the data collected by each instrument over the gray panels and color panels are used to study the correlation of the spectrometer systems.

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10. DATA LIBRARY

The LACIE Field Measurements Project, under the sponsorship of the Earth Observations Division, NASA/JSC, was begun in the fall of 1974 to acquire, process, and make available to researchers agricultural remote sensing data. As a result, one of the most comprehensive remote sensing research data sets has been assembled in the Field Measurements Data Library located at Purdue/ LARS. The general organization of the data library is illustrated in figure 13.

The field measurements data library catalog provides information on data available from the library. Its purpose is to describe the data by site, date, and sensor.

The catalog is divided into separate volumes -- one for each crop year during which data were collected. Volume I provides information for the 1974-75 crop year and is complete; no further changes are expected in this volume. Volume II is for the 1975-76 crop year.* Volume III is for the 1976-77 crop year.†

Each volume of the data catalog consists of four levels of increasing specificity. The first level is the Summary, the second level is the Record, the third level is the Index, and the fourth level is the Listing.

The Summary of field measurements data lists the data collected by the major sensor types for the mission over each of three test sites.

The Record of field measurements data lists the dates that data were collected over the test sites and provides a record of which data have been processed to the point that they are available for users. This section is organized according to test site and location of data collection (ITS, experiment station, or modeling field).

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*Issued in December 1976 and updated in August 1977.

†Issued in early 1978.

FIELD MEASUREMENTS DATA LIBRARY

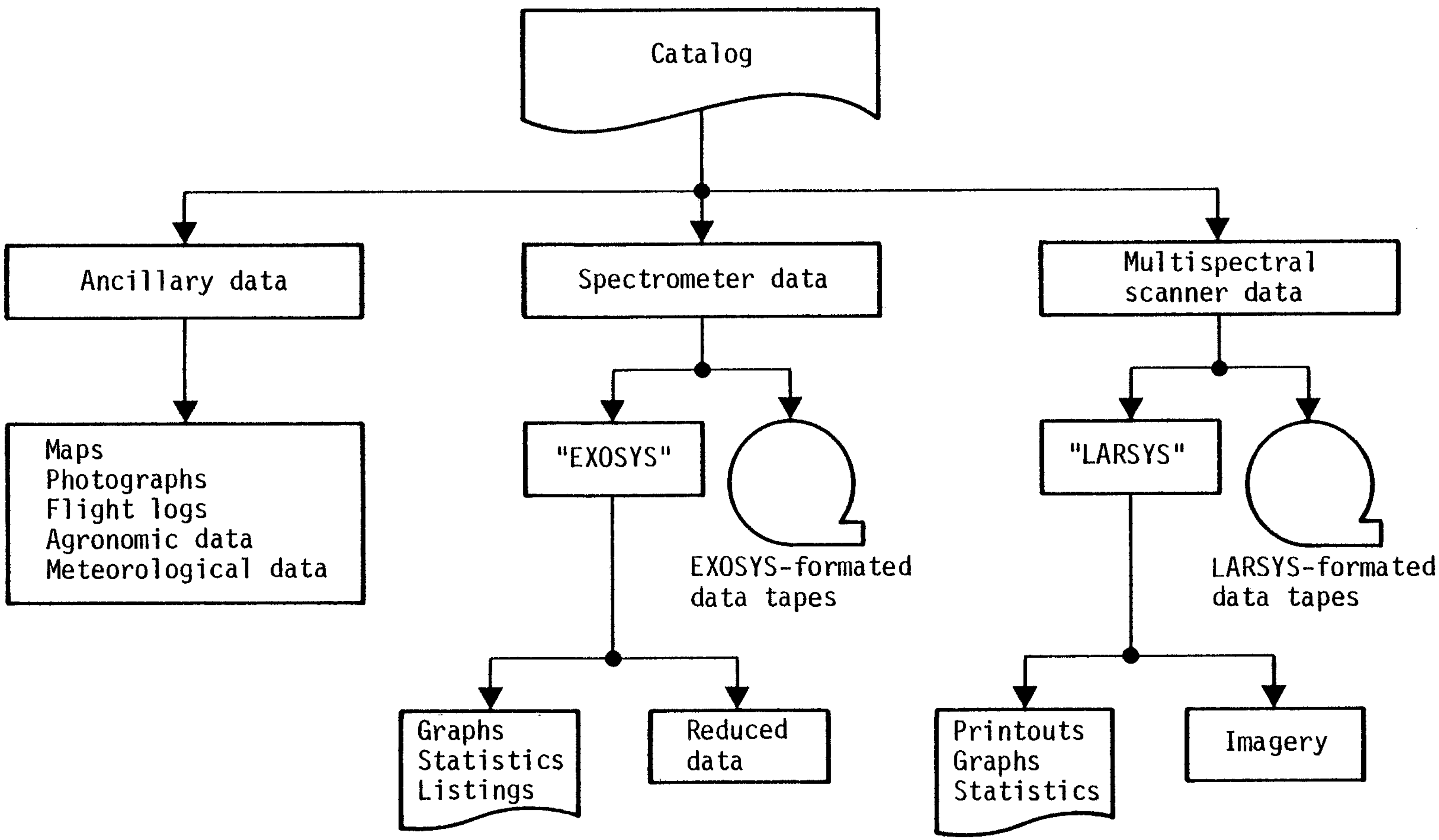

Figure 13.– Organization of field measurements data library. EXOSYS and LARSYS are Purdue/LARS software systems to analyze spectrometer and multispectral scanner data.

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The Index of field measurements data lists the data collected by sensor type; i.e., Landsat, aircraft, FSS, Exotech 20C, Exotech 20D (1975 only), and Exotech 100. The Landsat data are listed by site and date; the aircraft and FSS data are listed by site, date, and flightline; the truck-mounted spectrometer data are listed by site, date, and experiment; and the tripod-mounted radiometer data are listed by site, date, and time.

The fourth level of the data catalog, a computer printout, is a Listing of the information (i.e., observation number, location, date, time, scene type, instrument) required to access individual spectra. It is not included in the catalog itself but is available upon request from Purdue/LARS.

Appendix I of the catalog contains information pertaining to the location of the test sites and flightlines. Appendix II describes the treatments (plots) for which data were acquired at the agriculture experiment stations. Appendix III briefly describes the supporting agronomic, meteorological, and atmospheric measurements. Appendix IV gives a summary of the LACIE field measurements sensor specifications and operational characteristics.

The formats of the data are either imagery, hard copy outputs (as tables), or nine-track computer compatible tapes. The CCT's for the Landsat and airborne multispectral scanner data are in LARSYS Version 3 format. These data are proportional to the scene radiance; i.e., the data have not been altered from the initial processing performed at the institutions that operated the sensors. The CCT's containing the spectrometer or interferometer data (FSS, Exotech 20C, and Exotech 20D) are in EXOSYS format. These data are calibrated in bidirectional reflectance factor. Also, each observation on the EXOSYS tapes has a header record containing the supporting agronomic, meteorological, and atmospheric observations.

After the data are processed and logged into the library, they are routinely sent to investigators requiring the data for their NASA/JSC-funded analysis tasks. A mechanism to provide data to other interested researchers, at other NASA centers as well as other organizations, has been defined by the NASA/Earth Resources Program Office and JSC. Information on procedures for obtaining data may be obtained from the NASA Project Manager.

11. SCHEDULE

The schedule of Field Measurements Project activities for 1976-77 is shown in figure 14 and table IV.

The FSAS operated by JSC and Lockheed Electronics Company will collect data at Garden City, Kansas, during three 1-week missions between mid-September and early November and eight missions between mid-March and early July. LARS will collect data with the Exotech 20C during five 2-week missions from mid-May to late August at the Williston, North Dakota, test site.

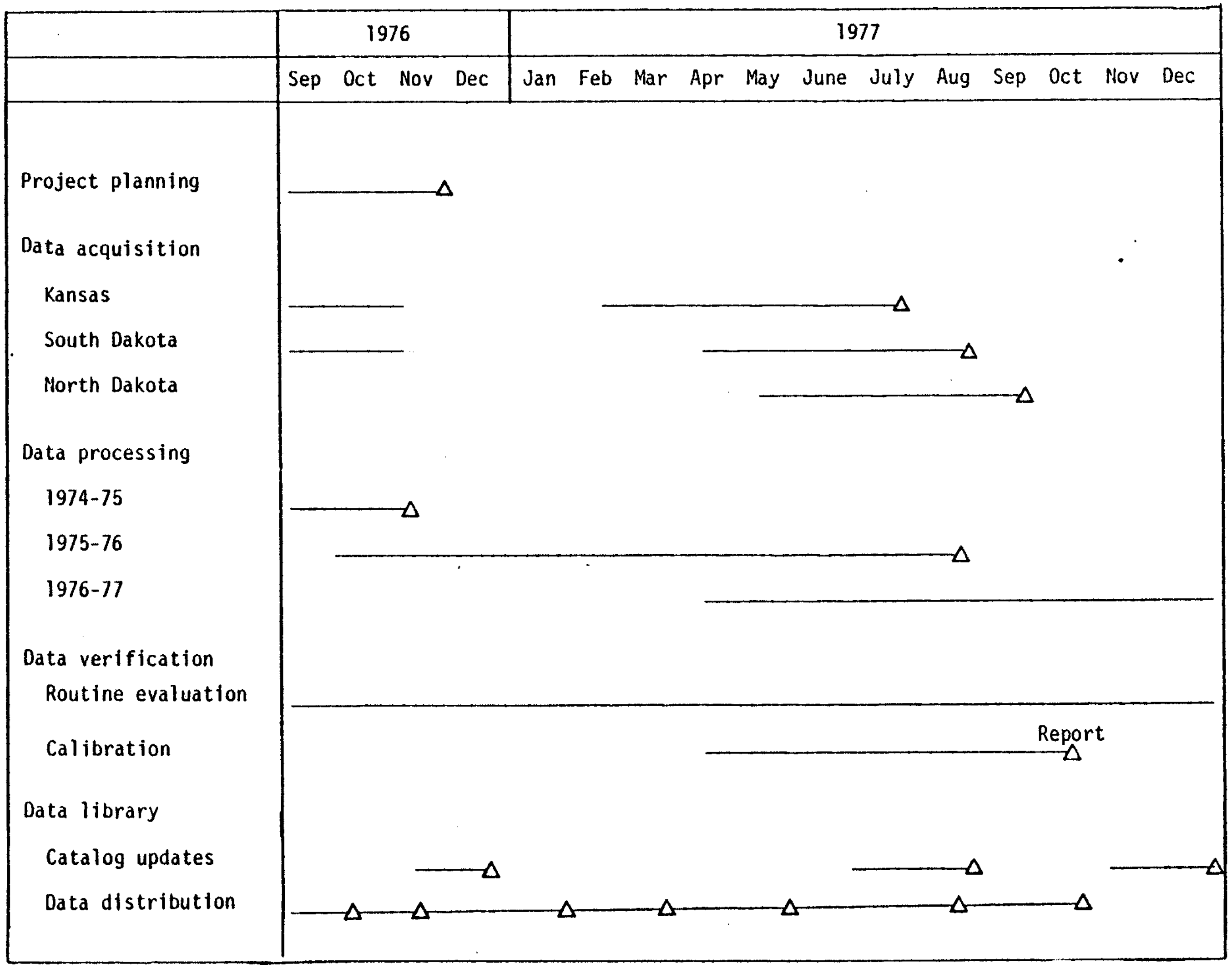

Figure 14.— Schedule of major activities of the Field Measurements Project, 1976-77.

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TABLE IV.— HELICOPTER AND AIRCRAFT MISSION WINDOWS FOR 1976-77

Test site		
Kansas	South Dakota	North Dakota
1976		
Sep. 27-30	Sep. 20-24	
Oct. 13-15	Oct. 18-22	
Nov. 2-5		
1977		
Mar. 8-11	Apr. 19-22	May 6-8
Mar. 26-29	May 10-13	May 24-26
Apr. 13-16	Jun. 1-3	Jun. 11-13
May 1-3	Jun. 15-18	Jun. 29-Jul.1
May 19-21	Jul. 6-9	Jul. 17-19
Jun. 6-8	Jul. 26-29	Aug. 4-6
Jun. 24-26	Aug. 16-19	Aug. 22-24
Jul. 12-14		

12. PROJECT ORGANIZATION AND MANAGEMENT

A LACIE Field Measurements advisory team was established at the beginning of the program to provide guidance to NASA/JSC and Purdue/LARS in the planning and implementation of field measurements to support LACIE research. Under this guidance, a substantial data library has been established which is unique in the degree to which spectral measurements from several sensors are mutually calibrated and supported by simultaneous observations of the soils, crops, and atmospheric conditions.

To assure continuing responsiveness of the Field Measurements Project to LACIE and other research organizations, the membership of the team is periodically changed. Current membership of the advisory team is as follows:

Michael McEwen, JSC/SF3, Project Manager
Marvin Bauer, Purdue/LARS, Technical Manager
Jon Erickson, JSC/SF3
Glenn Boatwright, USDA/Agricultural Research Service (JSC/SF3)
David Thompson, JSC/SF3
Keith Henderson, JSC/SF4
William Malila, ERIM
J. C. Harlan, TAMU
H. Clark Ison, USDA/ASCS (LACIE)

Project management is provided by NASA/JSC; technical coordination and management is provided by Purdue/LARS. The primary responsibilities for implementation of the project are as follows:

Purdue/LARS

- Technical coordination
- Data acquisition -- Williston, North Dakota, Agriculture Experiment Station (Exotech 20C)
- Data evaluation and verification
- Data processing and reformating
- Data library and data distribution

NASA/JSC

Project management

Data acquisition -- intensive test sites (MMS and FSS)

Data acquisition -- Garden City, Kansas, Agriculture Experiment Station (FSAS)

Data evaluation and verification

Processing of MMS, FSS, and FSAS data

USDA/ASCS

Ground data collection

TAMU

Modeling field measurements, Finney County, Kansas

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