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A CROPS AND SOILS DATA BASE FOR SCENE RADIATION RESEARCH

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ABSTRACT

Development of a crops and soils field research data base was initiated in 1972 at Purdue University's Laboratory for Applications of Remote Sensing and expanded in the fall of 1974 by the NASA Johnson Space Center as part of the Large Area Crop Inventory Experiment. The primary purpose for the data base is to provide fully annotated and calibrated multispectral sets of spectral, agronomic, and meteorological data for agricultural remote sensing research.

The data base presently includes over 200,000 truck-mounted and helicopter-borne spectroradiometer and multiband radiometer observations and 400 flight lines of aircraft scanner data. These data are supplemented by an extensive set of agronomic and meteorological data acquired during each mission.

The data form one of the most complete and best documented data sets acquired for remote sensing research. Thus, they are well-suited to serve as a data base for research to: (1) quantitatively determine the relationships of spectral and agronomic characteristics of crops and soils, (2) define future sensor systems, and, (3) develop advanced data analysis techniques. The data base which has become an integral part of the AgRISTARS Supporting Research Project data base, is unique in the comprehensiveness of sensors and mission over the same sites throughout several growing seasons and in the calibration of all multispectral data to a common standard.

I. INTRODUCTION

Mankind is becoming increasingly aware of the need for better management of earth's resources - atmosphere, water, soil, vegetation, and minerals to produce

adequate food supplies for an increasing world population. Agricultural crop production is highly dynamic in nature and dependent on complex interactions of weather, soils, technology and socio-economics. Accurate and timely information on crops and soils on a global basis is required to successfully plan for and manage food production. The repetitive, synoptic view of earth provided by satellite-borne sensors such as Landsat MSS provide the opportunity to obtain the necessary information on soil productivity, crop acreage and crop condition. For example, the Large Area Crop Inventory Experiment established the feasibility of multispectral remote sensing to inventory and monitor global wheat production¹.

But to fully develop the potential of multispectral measurements acquired from satellite or aircraft sensors to monitor, inventory and map agricultural resources, increased knowledge and understanding of the spectral properties of crops and soils in relation to their physical, biological and agronomic characteristics is needed. Quantitative understanding of the relationships between the spectral characteristics and important biological-physical parameters of crops and soils can best be obtained by carefully controlled studies of fields and plots where complete data describing the condition of targets are attainable and where frequent, timely spectral measurements can be obtained.

Development of a crops and soils scene radiation research data base was initiated in 1972 at Purdue University and expanded in the fall of 1974 by the NASA Johnson Space Center with the cooperation of the U. S. Department of Agriculture as a part of the Large Area Crop Inventory Experiment². More recently the data base has continued as part of the AgRISTARS Supporting Research Project. The primary purpose for development of the

data base is to provide fully annotated and calibrated multispectral sets of spectral, agronomic, and meteorological data from experimental plots and commercial fields for agricultural remote sensing research.

Since 1974, field research data have been obtained at ten test sites in Indiana, Iowa, Kansas, Nebraska, North Dakota, South Dakota, and Texas over many crops including spring and winter wheat, barley, corn, soybeans, sorghum, sunflowers, hay and pasture, and fallow ground. In addition, the data base includes laboratory measurements of 250 different soils from 39 states. The spectral measurements include data collected by nine different spectroradiometer and multiband radiometer systems mounted on truck and helicopter platforms and three different aircraft multispectral scanner systems (Figure 1). The spectral measurements include the 0.4-2.4 μm wavelength portion of the electromagnetic spectrum. Additionally, there are some spectral measurements for the 2.7 to 14.0 μm wavelength range.

The scene radiation experiments, measurements in the data base, spectral data calibration and data base access are described in this paper.

II. EXPERIMENTS

The critical component behind the development of the crops and soils scene radiation data base has been the experiment design. Agronomists, engineers, and statisticians have developed experiments which will provide the data needed to answer questions remote sensing researchers are pursuing. Data have been obtained to date for ten test sites across the Midwest and Great Plains states for over 35 different experiments (Tables 1 and 2).

The experiments include multiyear studies of the relationship of reflectance to crop canopy variables and agronomic practices such as development stage, leaf area index, soil background, plant population, and cultivar. Other experiments include studies of the relationships of nutrient or moisture stress and reflectance and radiant temperature of crops and studies of canopy reflectance as a function of canopy geometry, illumination angle, and view angle.

Two kinds of test sites have been used for the experiments: controlled experimental plots and commercial field

sites. The data from experiments in commercial field test sites provide a measure of the natural variation in the temporal-spectral characteristics of the cover type. The data from experiments in controlled plots where only two to four known factors are varied and more detailed, quantitative descriptions of the crops and soils can be obtained, enable more complete understanding and interpretation of the spectra collected from commercial fields.

The experiments for which spectroradiometer and/or multiband radiometer data have been collected are described in the Crops and Soils Field Research Data Base: Experiment Summaries (3). The summary includes for each experiment:

- Experimenter
- Location
- Experiment description
- Spectral measurement instrument(s)
- Dates data collected
- Number of spectral observations
- Illumination conditions
- Measurement codes
- Computer library tape(s)

III. MEASUREMENTS IN THE DATA BASE

The measurements in the data base include spectral, agronomic, and meteorological data (Table 3), along with information describing the experiment design and sensor (Table 4). The spectral data available in the data base have been obtained by laboratory spectroradiometers, truck- or helicopter-mounted spectroradiometers and multiband radiometers, and aircraft multispectral scanners (Table 5). For those experiments conducted over commercial fields Landsat MSS data are also available.

The spectral data obtained by the spectroradiometers and multiband radiometer systems are processed into comparable units, bidirectional reflectance factor, in order to make meaningful comparisons of data acquired by the different sensors at different times and locations. A description of the procedure to calibrate the spectral data obtained by the spectroradiometer and multiband radiometer systems is given in the next section. The data from the multispectral scanner systems are in their original units which are approximately linearly related to scene radiance.

The multispectral scanner data have been obtained at altitudes of 3,000 and 7,000 meters above the ground. Supporting

Table 1. Crops and soils scene radiation research commercial field test sites and experiments.

Test Sites and Experiments	Year
Webster Co., IA corn-soybeans cultural practices	1979-81
Finney Co., KS winter wheat cultural practices	1975-77
Cass Co., ND spring wheat, barley, sunflower, soybean cultural practices	1980-81
Williams Co., ND spring wheat, pasture, fallow, cultural practices	1975-77
Hand Co., SD spring and winter wheat cultural practices	1976-79
Wharton, Co., TX cotton, rice, soybean cultural practices	1980

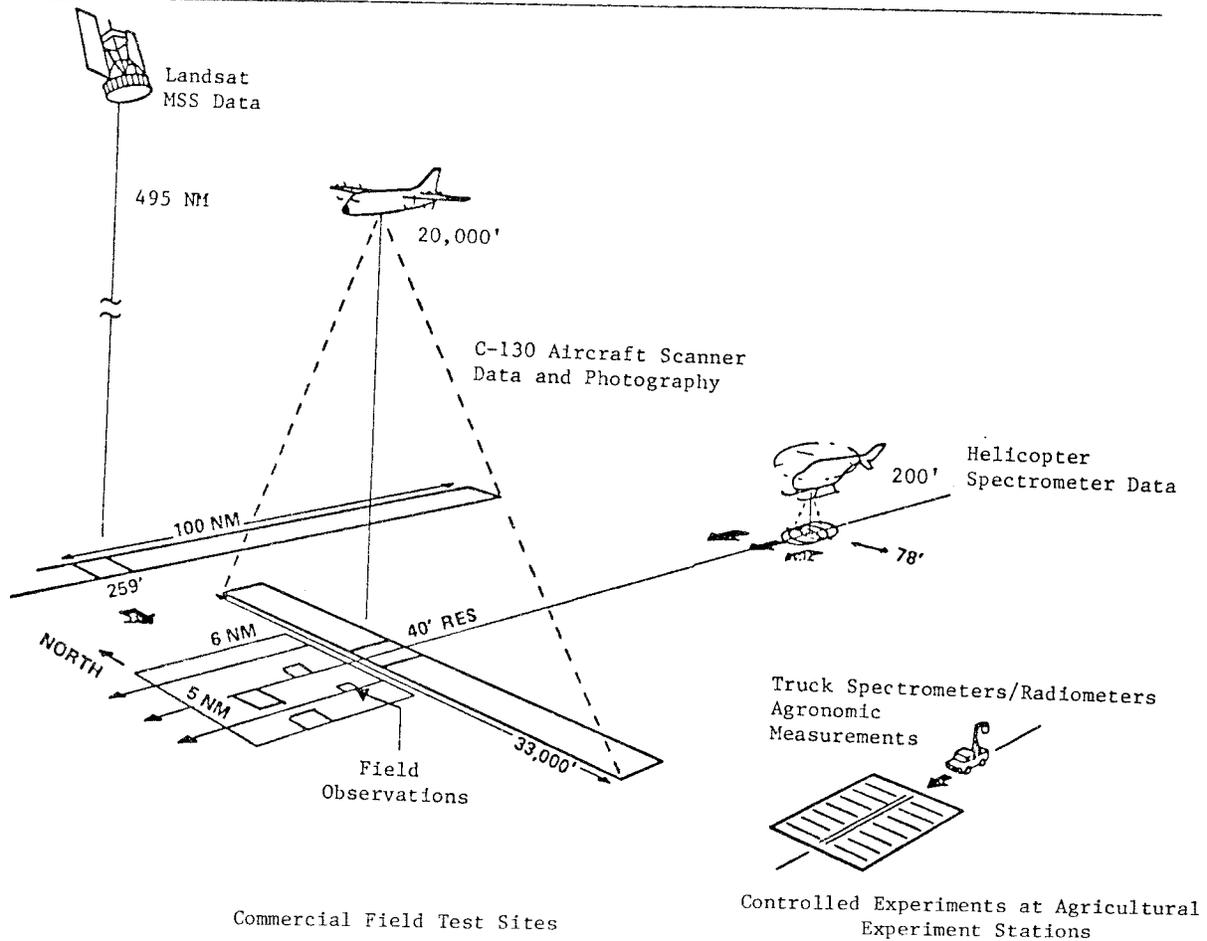


Figure 1. Schematic illustration of multistage approach for acquisition of field research data.

Table 2. Crops and soils scene radiation research controlled experiment plot test sites and experiments.

Test sites and Experiments	Years
West Lafayette, IN, Purdue Agronomy Farm	
corn moisture stress	1978-79
corn nitrogen fertilization	1978-79
corn potassium and phosphorous fertilization	1978
corn/soil background	1978-79
corn leaf blight	1972, 79
corn cultural practices	1979-81
crop row direction-soybeans, wheat, sorghum	1979-81
soybean potassium and phosphorous fertilization	1978
soybean cultural practices	1978-81
winter wheat nitrogen fertilization	1979-80
winter wheat disease	1980-81
soybean sun-view angle canopy modeling	1980
soybean variety	1980-81
sunflower cultural practices	1981
sorghum cultural practices	1981
sensor altitude	1979
Garden City, KS, Agricultural Experiment Station	
small grains	1975-77
winter wheat variety	1975
winter wheat residue management	1975
irrigated & dryland winter wheat	1975-77
Sandhills, NE, Agricultural Research Laboratory	
corn and soybean moisture stress	1979-81
Williston, ND, Agricultural Experiment Station	
small grains	1975-77
spring wheat cultural practices	1975-77
other crops	1975-77
spring wheat sun-view angle canopy modeling	1975-76
'U.S. & Brazil'	
laboratory study of 250 soil types	1978

the scanner data is 9-inch color infrared film. The helicopter-mounted spectroradiometer and multiband radiometer data have been obtained from an altitude of 60 meters. Supporting the measurements obtained from the helicopter platform are 70-mm color film of the test site. The data collected by the instruments mounted on truck platforms have been obtained from 4 to 10 meters above the ground. Vertical and oblique 35-mm photographs of the plots supplement the spectral data.

The meteorological measurements available for the time period that the spectral measurements were made include air temperature, wind speed and direction, relative humidity, barometric pressure, and cloud cover (Table 3). Additional meteorological data are available from NOAA or university weather stations near the test sites.

There are over 100 different agronomic parameters that have been measured (Table 3). The agronomic measurements made for a given experiment depend on the purpose of the experiment; therefore, all parameters are not measured for each experiment. For example, leaf nitrogen concentrations were collected for only the corn nitrogen experiment and canopy geometry measurements are made only for the canopy modeling experiments. However, a basic set of crop measurements is made for all controlled experiments (marked with asterisks in Table 3).

The present data base includes more than 300 dates and 170,000 observations of spectroradiometer data, 100 dates and 30,000 observations of multiband radiometer data, and 70 dates and 400 flight lines of aircraft scanner data. The data are stored on computer compatible tapes. Other data included in the data base are flight logs, field maps, and plot maps.

A summary of the spectral data collected and the dates data were collected are given in the Field Research Catalogs⁴.

IV. CALIBRATION OF SPECTRAL DATA

The spectral data obtained by the spectroradiometer and multiband radiometer systems are processed into comparable units, reflectance factor. A reflectance factor is defined as the ratio of the radiant flux actually reflected by a sample surface to that which would be reflected into the same reflected beam

geometry by an ideal (lossless) perfectly diffuse (Lambertian) standard surface irradiated in exactly the same way as the sample⁵.

The field calibration procedure consists of the comparison of the response of the instrument viewing the crop or soil to the response of the instrument viewing a level reference surface. For small fields of view (less than 20 degrees full angle) the term bidirectional reflectance factor has been used to describe the measurement: one direction being associated with the viewing angle (usually 0 degrees from normal) and the other direction being the solar zenith and azimuth angles. The spectroradiometer and multiband radiometer systems use reflectance reference surfaces with known reflectance properties. The truck-mounted systems use 1.2 meter square painted barium sulfate panels for a reflectance reference surface and the helicopter-mounted systems use a 6 x 12 meter white canvas panel.

The spectral data were obtained following well defined field procedures (6). Key components of this procedure are:

- frequent observations of the reflectance reference panel - at least every 10 to 20 minutes,
- instrument aperture is sufficiently distant from the scene - at least 3 meters above the top of the canopy,
- collect data when solar elevation angles are above 45 degrees, except for modeling experiments,
- no clouds are in the vicinity of the sun, and
- the reflectance reference surface is viewed in the same manner as the scene.

Another key component in calibrating the spectral data to bidirectional reflectance factor is that the non-Lambertian properties of the reference panels are taken into account⁶. The reflectance of the barium sulfate panel is compared to that of pressed barium sulfate in the laboratory at Purdue/LARS using a bidirectional reflectance factor reflectometer for illumination zenith angles of 10 to 55 degrees⁷. An extensive set of calibration measurements are kept on the reflectance reference surfaces.

Table 3. Measurement types and parameters included in the crops and soils scene radiation research data base.

Measurement Types and Parameters

Spectral	Soil description
spectral reflectance factor	order
spectral thermal radiance	suborder
radiant temperature	great group
photographs	subgroup
counts proportional to radiance (MSS data)	particle size class
	contrasting particle size class
	mineralogy class
Meteorological conditions	temperature regime
air temperature	soil series name
wet bulb temperature	horizon
barometric pressure	moisture regime
relative humidity	drainage class
cloud cover	slope class
wind speed & direction	erosion phase
optical depth	physiographic position
total incident radiation	parent material
	soil elevation
Crop description	natural vegetation or crop
*species	site location
*variety	soil moisture tension
*maturity stage	water content
*row width	munsell color
*row direction	textural class designation
*planting date	USDA particle size distribution
emergence date	erosion factor
days since planting	wind erodibility group
*plant count	liquid limit
fruit count	plastic limit
plant height	plasticity index
leaves per plant	activity
leaf condition	liquidity index
*ground cover	shrinkage limit
*dry biomass of leaves, stems, fruit	shrinkage ratio
*fresh biomass	volumetric shrinkage
plant moisture	linear shrinkage
*leaf area index	compression index
*grain yield	ASTM particle size distribution
grain test weight	specific gravity
grain moisture content	AASHO soil classification
moisture stress	unified soil classification
nutrient deficiency	organic carbon
weediness	extractable bases:
disease infestation	calcium
insect infestation	magnesium
hail or wind damage	sodium
lodging	potassium
previous field/plot use	extractable acidity
canopy geometry	cation exchange capability
leaf nitrogen concentration	base saturation
canopy color	iron oxide
	available phosphorous
	available potassium

* Denotes basic set of crop measurements.

Table 4. Other descriptive information included in the crops and soil scene radiation research data base.

Information Types and Parameters	
Spectral calibration	Experiment description
calibration observations	experiment number
calibration table number & code	experiment name
reformatting date	principal investigator
	scene type
Spectral measurement geometry	location name
illumination source	latitude & longitude
irradiance zenith & azimuth angles	flightline
view zenith & azimuth angles	date & time spectral data
distance to ground	collected
	field & plot number
Instrument description	replication number
instrument name	field area
scan rate	mission logs
focal distance	maps
field of view	verification reports
detector name	
gain & electronic filter settings	
facility operating instrument	
data quality values	

Table 5. Summary of major spectral sensor systems used for acquisition of data for crops and soils scene radiation research data base.

Platform and Sensor	Number of Bands	Spectral Range (μm)	Crop Years
Aircraft Multispectral Scanners			
24 Channel Scanner (MSS)	22	0.38-13.00	1975-76
Modular Multispectral Scanner (MMS)	11	0.37-13.00	1975-79
Thematic Mapper Simulator (NS001)	8	0.47-12.40	1979-81
Helicopter-mounted Spectroradiometer			
NASA/JSC Field Spectrometer System	72	0.40-14.00	1975-81
Helicopter-mounted Multiband Radiometer			
NASA/JSC Barnes 12-1000 MMR	8	0.45-12.50	1981
Truck-mounted Spectroradiometers			
NASA/ERL Exotech 20D	201	0.40-2.40	1975
NASA/JSC Field Signature Acquisition System (FSAS)	201	0.40-2.40	1975-77
Purdue/LARS Exotech 20C	201	0.40-2.40	1975-80
Truck-mounted Multiband Radiometers			
Purdue/LARS Exotech 100	4	0.50-1.10	1977-81
Purdue/LARS Barnes 12-1000 MMR	8	0.45-12.50	1981
U. Nebraska Exotech 100	4	0.50-1.10	1981
U. Nebraska Barnes 12-1000 MMR	8	0.45-12.50	1981
Laboratory Spectroradiometer			
Purdue/LARS Exotech 20C	201	0.40-2.40	1974-81

V. DATA BASE ACCESS

The computer compatible tapes containing the spectral data, film, flight logs, and maps are stored at Purdue/LARS. The data are available to researchers upon approval by Purdue's contract monitor at NASA's Johnson Space Center. The data base can be accessed through the Purdue/LARS computer system or standard formatted sets of the data can be prepared for approved requests. To date, the data base has been used by more than 20 different university, government, and industrial institutions for remote sensing research.

The multispectral scanner data are stored on 9 track, 1600 BPI tapes in LARSYS version 3 format⁸. The scanner data can be accessed and/or analyzed on the Purdue/LARS computer system using the LARSYS version 3 or LARSYSDV software systems.

The spectroradiometer and multiband radiometer data are stored on 9 track 1600 and 6250 BPI tapes in LARSPEC format⁹ and can be accessed via the LARSPEC software system¹⁰. LARSPEC is a software system developed at Purdue/LARS to allow the researcher to make searches of the spectroradiometer and multiband radiometer data, and supporting agronomic and meteorological data and print, graph, and copy the data as required. Currently work is in progress to use a commercially available data base management system, ADABAS, to manage the data in a computer disk file format.

VI. FUTURE DIRECTION OF DATA BASE

The crops and soils scene radiation data base is currently being expanded for 1982 to include data from agricultural research stations at:

Kansas State University
Oregon State University
Texas A & M University
South Dakota State University
University of Minnesota
University of Kansas
CIMMYT, Mexico
USDA/AR, Bushland, Texas

Measurements at these test sites will be made with the new Barnes 12-1000 multiband radiometer which has eight spectral bands, including the Thematic Mapper bands. The additional test sites will provide a more varied base of climatological-weather, and crop cultural practices. Also, plans are being developed to include microwave

measurements of crops and soils experiments.

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Larry L. Biehl, research engineer in the Measurements Program Area at LARS, has a B.S. degree in electrical engineering and an M.S. degree in engineering from Purdue University. He has had roles in NASA's Skylab program as a data analyst, NASA's Thematic Mapper Study as project manager and analyst, the LACIE Field Measurements Project, and currently the AgRISTARS Supporting Research Project. His present roles include overseeing spectral data acquisition, calibration and correlation, coordinating entry of the field research data into the library and developing improved software for more efficient analysis of spectral data. Mr. Biehl is a member of IEEE.

Marvin E. Bauer is a Research Agronomist at Purdue University and holds degrees from Purdue University and the University of Illinois. He is program leader of Crop Inventory Research at the Laboratory for the Applications of Remote Sensing. He has had key roles in the design, implementation and analysis of results of several major remote sensing experiments including the 1971 Corn Blight Watch Experiment and the Large Area Crop Inventory Experiment. His research is on the spectral properties of crops in relation to their agronomic characteristics and the development and application of satellite spectral measurements to crop identification, area estimation and condition assessment.

Barrett F. Robinson, senior research engineer and Associate Program Leader of the Measurements Program Area at LARS, has B.S. and M.S. degrees in electrical engineering and mathematics from Purdue University. He participated in the design and has directed the implementation and operation of the field spectroradiometer system used by Purdue/LARS to acquire calibrated digital spectral data. He had a key role in the NASA LACIE Field Measurements project in defining and directing the spectral data acquisition by Purdue and NASA/JSC. He has been responsible for the development of a multiband radiometer for field research and has directed its procurement and training and coordination of users during 1981.

Craig Daughtry is a research agronomist with the Laboratory for Applications of Remote Sensing at Purdue University. He has B.S. and M.S. degrees in agronomy from the University of Georgia and a Ph.D. in crop physiology from Purdue University. Dr. Daughtry has actively participated in design, implementation, and analysis of crop inventory experiments. He is a member of the American Society of Agronomy, Crop Science Society of America, American Society of Photogrammetry and several honorary societies.

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David E. Pitts has degrees from the University of Oklahoma in Engineering Physics (B.S. 1961, M.S. 1964). He joined NASA/Johnson Space Center in 1963 to design atmospheric density models of the planets for heat shield design for Gemini, Apollo, Skylab, and advanced manned planetary missions. He returned to the University of Oklahoma to complete a Doctoral of Engineering degree in meteorology (1971). He has participated in the design and conduct of remote sensing experiment programs at NASA such as: Apollo 9, Skylab EREP, Landsat, LACIE, and various aircraft experiments. His current assignment is as Head of Radiation Characterization Section which is conducting research into remote sensing of crop identification, condition, and crop stage as a part of the Supporting Research Project of AgRISTARS.