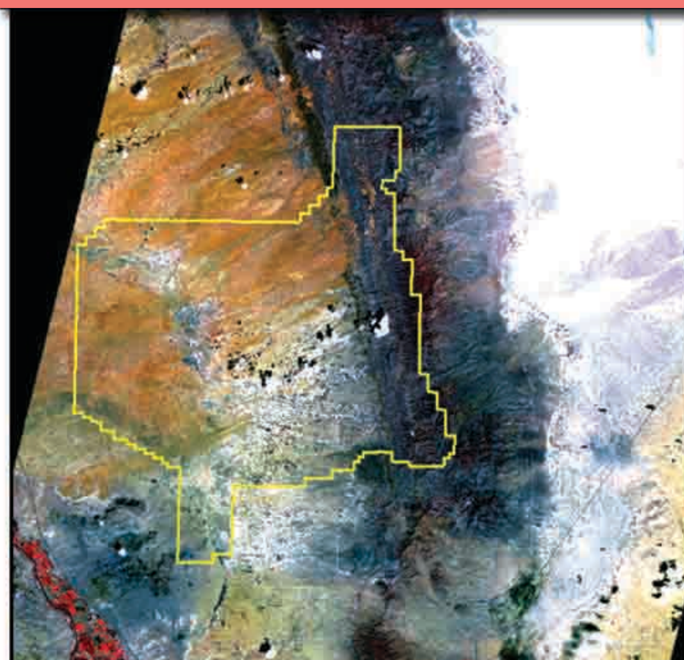
VOLUME 69, NUMBER 6 JUNE 2003

PE&RS

PHOTOGRAMMETRIC ENGINEERING & REMOTE SENSING

The official journal for imaging and geospatial information science and technology



Special Issue: ARS Remote Sensing Research

The Agricultural Research Service's Remote Sensing Program: An Example of Interagency Collaboration

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Abstract

Interagency programs have made it possible for scientists from the USDA, Agricultural Research Service (ARS) to conduct remote sensing research with researchers from various federal, state, and private organizations since 1965. Cumulative results from these cooperative studies have established the scientific basis for using remotely acquired imagery to better understand and manage the Earth's agricultural and natural resources. Examples of these partnerships include the 1965 Statement of Agreement between USDA and NASA that formally began ARS's remote sensing research, the Large Area Crop Inventory Experiment (LACIE, 1974), the ARS Wheat Yield Project (1976), Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS, 1980), the China Wheat Project (1983), and AG 20/20 (1999). This paper provides a brief overview of these collaborations.

Introduction

Interagency remote sensing programs have long enabled scientists from different government and private organizations to work together towards common goals—carrying out fundamental research and developing application strategies, while sharing measurement techniques and making data comparisons across various ecosystems and locations. Results from these collaborative efforts have stimulated widespread interest in applications of remote sensing technology for agricultural and natural resource management, and have provided the basis for sensor systems and approaches that are used today for monitoring the response of plants and soils to changing environmental conditions and various management options. This paper provides a historical perspective of several of these collaborations and sets the stage for the research described in this special issue of *Photogrammetric Engineering & Remote Sensing*.

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USDA/NASA Agreement—1965

The initiative to begin remote sensing research in the Agriculture Research Service (ARS) originates primarily from an "*Interagency Task Statement of Agreement between the USDA and NASA for Joint Research and Development Activities to Define Manned Earth-Orbital Experiments in Agriculture and Forestry*." This document was dated 19 February 1965 and signed by the Secretary of the U.S. Department of Agriculture (USDA) and the Administrator of the National Aeronautics and Space Administration (NASA). This interagency collaboration led to the development of an ARS remote sensing research program at Weslaco, Texas. The program's objectives were to characterize the reflectance and emission signatures of different land covers (crops and range) that would permit their identification using sensors on aircraft and satellite platforms. Weslaco was chosen for practical reasons—its long growing season permitted year around research on agricultural crops. While this Agreement was mainly between USDA and NASA, other federal and state agencies were also involved and the research eventually led to the definition of the first sensors carried on the Earth Resources Satellite-1 and Skylab (Miller, 1975).

LACIE—1974

Key events during the early 1970s drew attention to the socio-economic importance of accurate predictions of the world food supply and catapulted ARS' research at Weslaco headlong into finding practical applications for agricultural remote sensing. This awareness began in 1972, when the Soviet Union experienced widespread crop failures and purchased a massive amount of the stockpiled U.S. grain reserves—a move that caught world markets largely unaware, drove wheat prices up dramatically, and created grain shortages. Two years later when drought significantly reduced U.S. yields of wheat, corn, and soybean, grain prices soared even higher. In response, the USDA, NASA, and the National Oceanic and Atmospheric Administration (NOAA) began a joint program in 1974 called the Large Area Crop Inventory Experiment, or LACIE, which was intended to improve both domestic and international crop forecasting methods.

The Earth Resources Satellite (which was later renamed Landsat 1) had been launched in 1972, and this new civilian technology was brought to bear on the problem. For the

Photogrammetric Engineering & Remote Sensing
Vol. 69, No. 6, June 2003, pp. 615–618.

0099-1112/03/6906–615$3.00/0

first time, satellite-based remote sensing delivered synoptic views of crop response to weather-related phenomena in distant and previously inaccessible parts of the world. Although ARS was only marginally involved in the application and predictive efforts of the LACIE program, earlier research efforts by ARS scientists (Allen and Richardson, 1968; Knipling, 1970; Wiegand and Bartelli, 1971; Gausman *et al.*, 1973; Leamer *et al.*, 1975) helped establish the scientific basis for using spectral properties to determine crop cover and plant growth and development. Combined with historical trends in weather and planting patterns, the LACIE project soon demonstrated that satellite imagery could be used operationally to determine wheat area and forecast yields in both the U.S. and Soviet Union (Bauer, 1979; MacDonald and Hall, 1980; Hill *et al.*, 1980). It also opened the eyes of visionaries within ARS who dreamed of making this new technology available to the world at every level from policy makers to scientists and large corporate farming conglomerates to subsistence farmers.

ARS Wheat Yield Project—1976

Perceiving that USDA could contribute even more to the research effort that would improve wheat production forecasts, ARS created a multidisciplinary and multi-location group of scientists, the ARS Wheat Yield Project in 1976 (Willis, 1985). Some members of this group developed process-oriented models that quantified the effects of climate and culture on crop productivity, while others carried out agronomic experiments to test model performance. These experiments were conducted across a number of U.S. locations where wheat was the predominant crop (Wiegand *et al.*, 1992). Many of the group's scientists worked interactively with colleagues from NASA's Earth Sciences Branch and Purdue's Laboratory for Applications of Remote Sensing to determine how different sensors could be used to obtain information about plant growth and development. As part of this project, they acquired and helped design wideband radiometers and infrared radiation thermometers (Robinson *et al.*, 1979; Tucker *et al.*, 1981) and conducted workshops to teach others how to use them (Jackson *et al.*, 1980). These scientists then started making observations in their field experiments, and began to develop remote sensing methods for assessing normal plant condition and providing early warning of plant stress (Wiegand *et al.*, 1992). Their collective research forged a linkage among remotely sensed crop parameters, growth, development and yield models, and observations from satellite platforms being used to estimate crop yields on a world-wide basis (Wiegand *et al.*, 1991).

AgRISTARS—1980

A larger recognition of the potential for remote sensing in crop management began to emerge in the late 1970s and early 1980s during another joint program sponsored by the USDA, NASA, NOAA, the U.S. Department of Interior, and the Agency for International Development of the U.S. Department of State. Termed Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing, or better known by its acronym AgRISTARS, this program sought to determine the feasibility of integrating aerospace remote sensing technology into existing and future USDA missions (NASA, 1984; Hogg, 1986).

The AgRISTARS technical program consisted of eight broad projects spanning research from soil and crop condition assessment to early warning of plant stress, inventory of croplands, yield model development, and effects of pollution on plant growth. A considerable portion of AgRISTARS research was aimed toward developing a better understanding of how electromagnetic radiation interacted with agricultural targets, defining conditions under which observations might best be made, and deriving approaches for using this information to monitor plant condition. ARS scientists, many of them from the original ARS Wheat Yield Project, along with their counterparts from other USDA agencies, NASA, and the university system, played a significant role in expanding the applicability of remote sensing to agriculture during this period. The particular areas of ARS scientific involvement were in early warning and crop condition assessment (Boatwright *et al.*, 1985), yield model development (Baker *et al.*, 1985; Willis, 1985), soil moisture measurement (Jackson, 1986), and conservation and pollution (Rango *et al.*, 1985; Engman, 1986).

Not all AgRISTARS research was directly related to the use of remotely sensed imagery. Considerable research efforts were also focused on understanding and modeling plant growth and development because of its importance for determining the biophysical connection between remotely sensed information and plant growth. A number of mechanistic models of crop development and yield determination were developed, refined, and validated with experimental data acquired during the AgRISTARS project [e.g., the "CERES" models described by Jones *et al.* (1983) and Ritchie and Otter (1985)]. These models continued to be improved and are now used internationally to predict plant growth and development.

The capability to measure and monitor soil moisture is also important to understanding and predicting plant growth and in evaluating erosion potential. Conventional methods of measuring soil moisture were point specific and labor intensive. AgRISTARS researchers were tasked to investigate remotely sensed measures as an alternative or complementary way to determine soil moisture. They included water stress treatments in experimental protocols and made extensive measurements in the reflective and thermal regions of the electromagnetic spectrum. This research led to the development of the crop water stress index (CWSI) and guidelines for using infrared thermometry to detect and quantify plant response to soil available water and to signal irrigation timing (Jackson, 1982). Of particular interest for monitoring soil moisture was the microwave region of the spectrum, specifically in the L- and C-band frequencies. During the AgRISTARS project, a fundamental understanding of microwave sensing of soil moisture was achieved using sensor systems on ground, aircraft, and satellite platforms. (Engman and Jackson, 1983; Jackson *et al.*, 1984; Jackson, 1986).

Water supply forecasting from snow pack in the western United States is of great importance to agriculture and other user needs. Ground sampling methods are time consuming, costly, and can be dangerous to personnel involved. Thus, an additional objective of AgRISTARS was to evaluate remote methods for predicting both the areal extent and depth of snow pack. Here, microwave observations from polar orbiting and geostationary satellites proved useful (Rango, 1983; Rango, 1985; Rango, 1986), and these methods are now routinely used to accurately measure snow pack and rates of snow melt.

ARS scientists contributed literally hundreds of research reports and publications during the four-year duration of the AgRISTARS program, and scientific knowledge gained during the period remains a foundation for research today. Overviews of this research can be found in the *IEEE Transactions on Geoscience and Remote Sensing*, Volume GE-24, January 1986 (Hogg, 1986) and ARS AgRISTARS Annual Reports (Ritchie, 1981; Ritchie, 1982).

China Wheat Project – 1983

As part of a scientific exchange program that began in the 1980s between the USDA and China, a project was devel-

Table 1. Priorities for Research and Development Efforts within the Ag20/20 Program (McKellip, 2001).

Priority	Objective
Nutrient application	Optimal allocation of fertilizer to reduce input costs and improve production efficiency
Weed scouting/herbicide application	Effective weed detection and management to reduce herbicide costs and inputs
Insect scouting/insecticide application	Effective insect management to reduce pesticide costs and inputs
Irrigation/soil moisture information	Optimization of soil water resources and improved management of irrigation water
Yield	Development of tools to (1) optimize yield and (2) predict/forecast yield for marketing decisions
Soil characterization	Identification of soil management zones for improved decision making
Vigor/stress detection	Determination of crop response to varying field and weather conditions to improve decision-making process
Grain quality	Characterization of product-quality factors (oil, protein, lint, etc.) for appropriate harvest and marketing decisions
Next season preparation	Assessment of physical properties of fields after harvest to support planning of upcoming crop

oped to assess the impact of water and nitrogen on winter wheat production. Its purpose was to provide training for Chinese scientists on the conduct of agricultural experiments using modern technology. Standard protocols for data collection and archiving were instituted so that data could be freely moved among locations. Remote sensing was an integral part of this program, with multispectral reflectance and thermal emittance data being collected over a range of water and nitrogen treatments across five locations in the U.S. northern Great Plains wheat belt. Results were published in a special issue of *Agriculture and Forest Meteorology* (Rosenberg, 1988; Reginato *et al.*, 1988). Each of the locations participated in the joint analysis of all the information collected to evaluate the responses across locations. These data sets have been used to validate simulation models for wheat development, growth, and yield.

AG 20/20—1999

In 1999, a new agricultural remote sensing thrust emerged from discussions among NASA, USDA-ARS, Land Grant Institutions, and the four major U. S. commodity groups (corn, cotton, soybean, and wheat)(McKellip, 2001). From the onset, this program was unique because it included producer goals and concerns as a framework for research program development and integration. Workshops conducted with the commodity groups identified a number of priority areas that served to focus research goals (Table 1). The program was named AG 20/20 to denote the clearer vision of the total agricultural system that was achieved by interaction of the different participants. The overarching objective of the AG 20/20 program was to develop and disseminate simple, innovative information tools that would increase production efficiency, reduce economic risks, and decrease the environmental impacts of farming operations.

Research programs were developed in California and Mississippi on cotton management, in Illinois and Iowa on corn and soybean management, and in Montana on wheat management. Producers wanted to use remote sensing as part of their decision-making process when managing nutrients, weeds, insects, yields, and product quality. So, the research addressed problems such as field variation in crop response to nutrient management, the distribution of weed and insect populations within fields, and the response of the crop to different management decision scenarios. Remote sensing applications built upon the historical methods for remote detection of plant stress while placing this information within the context of field and farm decision making with which growers could relate. Input from the producers themselves helped guide the program toward products that could be rapidly incorporated into their decision-making process and further demonstrated the positive benefits of including the user community in the planning and evaluation process.

Concluding Statements

The Agricultural Research Service has been a very strong player in the development and utilization of remotely sensed information for monitoring and management of farm and natural resources. ARS, in collaboration with USDA programs and other federal and state agencies, has established a scientific basis for using remotely acquired imagery to better understand the physics, chemistry, and biology of the Earth's agricultural systems. In the process, ARS' research has benefited both science and humankind. Today, there are approximately 60 scientists working on various aspects of remote sensing science at 25 different ARS locations. This research is being conducted under the aegis of at least eight National ARS Programs (http://www.nps.ars.usda.gov/). Continued interagency cooperation and awareness of user needs will help ARS meet challenges of food and fiber production in the future.

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