IRRIGATED CROP MANAGEMENT UTILIZING REMOTE SENSING

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PROJECT SUMMARY

We propose to conduct agricultural water management research using remote sensing approaches with the following objectives: (1) Develop and critically assess methods for using reflected solar and emitted thermal energy to quantify temporal and spatial variations in crop response to water, nutrients, and pests. Special emphasis will be placed on developing algorithms that perform reliably regardless of plant phenology and biomass, and thus can be used for crop management purposes throughout the entire growing season. (2) Develop and improve irrigation scheduling methodologies that are responsive to actual crop evapotranspiration (ET) and irrigation requirements. Multispectral vegetation indices will be used to develop and test real time, basal crop evapotranspiration coefficients (K_{cb}) which are expected to provide significant improvements of actual crop ET prediction for use with irrigation scheduling procedures for cotton and wheat. (3) Develop methods for using remotely sensed observations in precision management of water, nutrients, and pests in irrigated crops. Remote data will be tested as a means to direct an efficient sampling routine. It will also be used in conjunction with simple and process-oriented crop growth and management models to provide spatial information needed to run the models with a minimum amount of input. Research accomplished during this project will result in improved methods for quantifying actual crop water and nutrient needs, as well as methods to detect water, nutrient, and pest related stresses. This will enable growers to make better informed, within-season management decisions about the need to irrigate, fertilize, or control pests on an "as needed" basis within their farms or fields and particularly in situations where variable rate technology is in use.

OBJECTIVES

1. Develop and critically assess methods for using reflected solar and emitted thermal energy to quantify temporal and spatial variations in crop response to water, nutrients, and pests.

   Spectral reflectance and thermal emittance properties of soils and plants will be used to detect environmental stresses that limit productivity of agricultural crops. Traditional vegetation indices such as the NDVI will be combined with other spectral information that is less sensitive to canopy biomass in order to reduce problems associated with partial canopy conditions and enable identification of water and nutrient related stresses throughout the entire growing season.

2. Develop and improve irrigation scheduling methodologies that are responsive to actual crop evapotranspiration and irrigation requirements.

   Basal crop coefficients (K_{cb}) will be derived from multispectral vegetation indices then refined to provide improved water management capabilities within the framework of accepted FAO-56 irrigation scheduling procedures. A two-dimensional Crop Water Stress Index (CWSI) which accounts for partial canopy conditions will be used to more accurately quantify real-time crop water use and map its spatial variability throughout the entire growing season.

3. Develop methods for using remotely sensed observations in precision management of water, nutrients, and pests in irrigated crops.

   Statistical and image analysis procedures will be used with multispectral reflectance and thermal emittance imagery of agricultural fields to guide efficient sampling ground procedures, define management zones, and generate maps of crop density and conditions related to water, nutrient, and pest stresses. Indices related to crop nutrient status, transpirational potential (*i.e.* K_{cb}), and water stress (CWSI) will be integrated into process-oriented crop models to predict spatial and temporal variability in plant response across a field and provide a framework for precision management of water and nutrients.

NEED FOR RESEARCH

Description of the Problem to be Solved

Industrialized nations are poised on the threshold of dramatic changes in the way natural resources are surveyed, monitored, and managed. Growers are being encouraged to increase their productivity per unit of land and water in order to feed a hungry world. Agricultural resource managers are recognizing within-field variability in potential productivity and seeking ways to customize their growing practices to exploit that variability (National Research Council, 1997). Environmental guidelines mandate more efficient and safer use of agricultural chemicals. As a result, today's farmers require an increasing amount of information on field and plant conditions to manage their crops in a sustainable and environmentally sensitive manner and still make a profit. Not only does this information need to be accurate and consistent, but it also needs to be available at temporal and spatial scales that match the farmer's capability to vary water and agrochemical inputs (*i.e.,* precision crop management).

A large body of research spanning the past three decades has demonstrated the potential for remote sensing (RS) to deliver this type of spatial and temporal information on soil and crop response to dynamic environmental conditions and management. Now, when combined with extraordinary advances in precise global positioning satellite (GPS) devices, microcomputers, geographic information systems (GIS), and enhanced crop simulation models, farmers can use remote sensing from ground, aircraft, and satellite platforms to monitor and manage their crops on a routine, cost-effective basis. The successful application of RS technology to agricultural resource management requires a basic understanding of how changes in plant growth, form, and function affect spectral reflectance and thermal emittance properties of crops in the field.

Beyond this fundamental requirement however, a number of significant problems still need to be overcome before RS will be able to deliver on promises made to consumers and agriculture towards the end of the last century. How, for example, can signals associated with plant water-, nutrient-, and pest stress conditions be discerned for certain when scenes are composed of varying amounts of plant and soil components? What is the best way for RS to provide additional spatial and temporal information needed to improve the performance of existing irrigation scheduling and crop growth simulation algorithms? These are research issues that are becoming more important as precision agriculture assumes a greater role in producing America's food and fiber. They are also examples of the problems that we propose to explore in this project's research plan. One has only to look at the somewhat disappointing failure rate among of commercial remote sensing ventures to recognize that this is high risk research that is best addressed through a long-term national research program.

Relevance to ARS National Program Action Plan

This project relates broadly to several components within the National Program for Water Quality and Management by providing approaches for monitoring the response of soils and crops to management practices and environmental conditions, for detecting the occurrence of growth-limiting plant stresses, and for quantifying biophysical processes such as evapotranspiration (ET) and absorption of solar energy used in photosynthetic pathways.

Objective 1 relates to the Irrigation and Drainage Management Component, Problem Area (PA) 2.1, Economical Irrigated Crop Production, Goal 1 - Develop water, pest, and nutrient management practices and technologies that protect the environment and improve the economic benefits of irrigation and drainage. Objective 1 also has linkages with National Program (NP) 204 Global Climate Change, and NP 305 Crop Production.

Objective 2 relates to PA 2.3, Water Conservation Management, Goal 1 - Develop technologies to quantify and control a broad range of water supplies and uses, and Goal 2 - Develop cultural and management practices for agriculture, turf, and urban landscape plantings that maximize the return for irrigation water used.

Objective 3 relates to PA 2.2, Precision Irrigated Agriculture, Goal 1 - Develop precision agricultural irrigation systems that incorporate water management strategies and remote sensing technologies into site-specific management for the production of agronomic and high-value crops, and PA 2.3, Water Conservation Management, Goal 3 – Develop improved agricultural practices and systems that mitigate the adverse effects of irrigation on water quality and the environment. Objective 3 also has links to NP 207, Integrated Agricultural Systems.

Potential Benefits

Research conducted in this project will result in improved methods for quantifying crop water, nutrient, and pest related stresses and actual irrigation water requirements. This will enable growers to make better informed, within-season management decisions regarding irrigation timing and delivery volumes, fertilizer needs and pest control on an "as needed" basis within their farms or fields. Farmers will be able to initiate remedial actions that will maximize economic benefits and minimize detrimental environmental impacts. Incorporating RS soil and plant information into crop irrigation, growth simulation, and management models will provide spatial information that is needed to use these models on a finer spatial scale for describing within field variability and will increase their utility for precision agriculture approaches such as generating variable rate fertilizer application maps. In addition, the enhanced models will add predictive capabilities to somewhat less frequent remote observations, an important benefit in regions where cloud cover interferes with regular satellite or aircraft coverage.

Anticipated Products

This project will result in new and improved RS approaches for identifying different types of plant stress and quantifying their intensity, regardless of plant biomass or phenological stage. Products for scheduling the timing and amounts of irrigation and fertilizer applications are also anticipated. Multispectral, real time crop coefficients for determining the seasonal course of actual crop ET will be developed for cotton, wheat, and alfalfa. The project will also lead to new methods for combining the spatial information from RS and the predictive capabilities of crop management models, and provide specific approaches for utilizing RS capabilities in the emerging field of precision agriculture.

Customers

Stakeholders who will benefit from the research include growers; crop, soil, and irrigation consultants; cooperative state extension personnel; commercial providers of RS products; and commercial entities and governmental agencies that control or regulate water supplies. Algorithms developed during the course of this research will have a direct bearing on yield prediction, and thus have potential use for agencies such as NASS or FAS who forecast yields over broad geographic regions. NASA and commercial RS providers will be active partners in developing practical farm management and regulatory applications of RS imagery.

SCIENTIFIC BACKGROUND: Refer to 2001 Annual Report

APPROACH AND RESEARCH PROCEDURES: Refer to 2001 Annual Report

PHYSICAL AND HUMAN RESOURCES: Refer to 2001 Annual Report.

Milestones and Expected Outcomes

Date	Research Objective or Area of Study		
	1. Crop Response	2. Irrigation Scheduling	3. Precision Agriculture
Oct. 2001	Scheduled Starting Time for Project		
Jan. 2002	· Concept paper on two dimensional indices (CCCI, WDI) written and submitted to journal (Clarke, Barnes, Pinter) · Manuscript on fAPAR and spectra from prev. FACE Expts. written and submitted to journal (Pinter) · Data from 2001 LiMIE Broccoli experiment used to confirm CCCI approach for detecting N stress in vegetable crop (Barnes, Clarke, Pinter) · Contingent on NASA funding to FACE Alfalfa CO_2 by H_2O experiment, crop planted (fall 2001), RS measurements underway. (Pinter, Kimball)	· Review and analyze spectral crop coefficient and ET_a/ET_o data from 1985-86 WCL Alfalfa Lysimeter Study. (Hunsaker, Pinter) · Ditto for FACE Cotton with goal of obtaining working spectral K_{cb} algorithms (Hunsaker, Pinter, Kimball, Wall) · Finalize experimental strategy for field tests of FAO-56 WDI and K_{cb} scheduling in cotton (All) · Develop and field test backpack radiometer/micromet pkg coupled with GPS for collecting ground-based georeferenced crop coef and WDI data. (Clarke)	· Journal paper incorporating CWSI index into CERES Wheat model written. (Barnes Pinter) · Cooperative research with Mississippi underway, preliminary results from 2001 LiMIE Cotton Experiments tabulated. (Barnes) · Select cotton model amenable to incorporating RS data. (Barnes, Kimball) · Explore approaches for obtaining aerial imagery in Prec Ag (Fitzgerald, Barnes, Clarke, Adamsen) · Test spatial interpolation techniques on existing images.
Jan. 2003	· Complete cotton experiment designed to validate WDI and CCCI. Tabulate, reduce, and analyze data. (All) · Analyze hyperspectral and CCCI data from FACE Wheat CO_2 by Nitrogen experiment (Pinter, Clarke) · Plan field plot study to answer specific questions in using spectral or thermal indices to detect water, nutrient, or pest stress	· Paper(s) summarizing crop coefficient findings for alfalfa & cotton written and submitted to journal (Hunsaker, Pinter) · 1st cotton irrigation experiment completed (Oct 2002), data tabulated and reduced (All) · Refine protocol as needed for 2nd cotton irrigation experiment	· Growth, yield, and water content from cotton field experiment used to validate prec ag approach using cotton model.
Jan. 2004	· Paper on use of CCCI or comparable index for monitoring N stress in wheat written and submitted to Journal. (Clarke, Pinter)	· 2nd cotton irrigation experiment completed, Oct 2003) data tabulated and reduced. (All) · Finalize experimental strategy for field tests of FAO-56 WDI and K_{cb} scheduling in wheat (All) · 1st wheat irrigation scheduling experiment begun (Nov 2003) (All)	· Growth, yield, and water content from wheat field experiment used to validate prec ag approach using CERES model. · Manuscript on “directed” sampling methods using RS data written. (Barnes et al.)
Jan 2005	· Paper validating CCCI or comparable index for monitoring N stress in cotton written and submitted to Journal. (All) · Data analysis, publication, and presentation of results as significant outcomes arise. (All)	· 1st wheat experiment completed (May 2004), data reduced, tabulated, and analyzed (All) · Refine protocol as needed for 2nd wheat irrigation experiment · 2nd wheat irrigation experiment begun (Nov 2004) (All)	· Paper on techniques for incorporating RS into cotton growth model written and submitted to journal. (Barnes, et al.)
Jan 2006	· Data analysis, publication, and presentation of results as significant outcomes arise. (All)	· 2nd wheat experiment completed (May 2005), data reduced, tabulated, and analyzed (All) · Publication and presentation of results (All)	· Data analysis, publication, and presentation of results as significant outcomes arise.
Sept. 2006	End of Proposed Project Plan		

PROGRESS:

Research was conducted to determine whether remotely sensed, multispecteral vegetation indices such as the NDVI, could provide reliable estimates of crop coefficients for determining water use and scheduling irrigations in cotton. ARS researchers from the U.S. Water Conservation Laboratory and Western Cotton Research Laboratory in Phoenix AZ with others from The University of Arizona, initiated this study which compares the standard FAO-56 with a proposed NDVI-based scheduling strategy across 3 cotton plant populations and 2 levels of nitrogen fertilization. Experimental protocol included regular ground- and aircraft-based observations of cotton spectral and thermal properties as well as frequent measures of soil water content, cotton water relations, agronomic propertieies, and cotton insect behavior. Remotely-sensed crop coefficients are expected to offer a means to improve estimation of evapotranspiration by providing real-time feedback of crop water use as influenced by local atmospheric conditions and spatial variation in soil properties, stand density, nutrient availability, and crop development.

The procedures for identifying different soil or vegetation zones in multispectral aerial images for follow-up field sampling are rather subjective, often relying on an analyst's visual interpretation of spectral features instead of employing more rigorous and repeatable statistical analysis. In cooperation with ARS scientists from the George E. Grown Jr. Salinity Laboratory and with partial support under a reimbursable agreement with Mississippi State University, ARS researchers from the U.S. Water Conservation Laboratory in Phoenix AZ applied statistical software that was originally developed for use with spatially distributed, soil electrical conductivity data to calibrated, multispectral imagery collected over an Arizona cotton field. The software automated the process of selecting an unbiased set of field coordinates for detailed soil and plant sampling and reduced the total number of samples that would otherwise be required. This procedure standardizes approaches for directing field sampling efforts and provides a robust method for establishing predictive relationships between remotely-sensed information and ground paramters.

Hyperspectral remote sensing approaches offer potential improvements for diagnosing and delineating infestations of serious pests like the strawberry spider mite in cotton which rarely occurs uniformly across an entire field and can be notoriously difficult to control. An ARS researcher from the U.S. Water Conservation Laboratory in Phoenix AZ applied an image processing procedure that is new to agriculture, called spectral mixture analysis, to determine the extent of mire problems within large cotton plots at the Shafter Research and Extension Center in Shafter CA. Using an innovative, liquist crystal tunable filter CCD camera, hyperspectral images of mite-infested and healthy leaves plus images of sunlit and shaded soils were used to find affected cotton in images acquired by the AVIRIS sensor on a high altitude NASA reconnaissance plane. With variable rate technology, a farmer could apply chemicals selectively only to those areas where mites have become a problem, reducing the total amount of pesticides used per field as well as allowing beneficial insects in unaffected areas to recolonize sprayed areas and reducing the chances of secondary pest outbreaks.

Growers' awareness of within-field spatial variability in crop production as measured by yield monitors is increasing the demand to understand the sources of that variability so appropriate adjustments in the following year's management decisions can be made. ARS researchers from the U.S. Water Conservation Laboratory in Phoenix AZ, with support provided via a reimbursable agreement with Mississippi in Phoenix AZ, with support provided via a reimbursable agreement with Mississippi State University, used calibrated aerial imagery obtained over a 3.4 ha cotton field at 2-3 week intervals during the growing season to monitor changes in the spatial growth patterns of the crop. Spatial variations in final yield were related to soil textural patterns of the crop. Spatial variations in final yield were related to soil textural differences observed in early season imagery, while cultivator damage and poor seedling vigor were apparent in mid-season imagery. This study provides producers, consultants and image providers with examples of how remotely-sensed data can aid in the interpretation of end-of-season yield maps.

ARS scientists from the U.S. Water Conservation Laboratory in Phoenix AZ have designed and assembled an aircraft sensor package consisting of a custom filtered, 3 CCD camera (MS3100, Duncan Technologies, Inc.), a thermal scanner (Inframetrics Model 760), and a color digital camera. Beginning with the FY2002 field season, the system was flown successfully on a 2 to 3 week schedule, acquiring imagery from experimental cotton and guayule fields along with reflectance factors and apparent temperatures of ground basede calibration tarps. Data reduction was typically completed on the date of acquisition and results were used to direct field sampling the following morning. Additionally, a custom-
built liquid crystal tunable filter, digital camera system capable of imaging in 10 nm increments from 400-1100 nm is being evaluated.

Publications:

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