ANNUAL RESEARCH REPORT
U.S. WATER CONSERVATION LABORATORY

2003

USDA - AGRICULTURAL RESEARCH SERVICE
Phoenix, Arizona

ANNUAL RESEARCH REPORT

2003

U.S. WATER CONSERVATION LABORATORY
U.S. Department of Agriculture
Agricultural Research Service
4331 E. Broadway Road
Phoenix, Arizona 85040

Telephone: (602) 437-1702
FAX: (602) 437-5291
E-mail: bclemmens@uswcl.ars.ag.gov
Website: www.uswcl.ars.ag.gov

TABLE OF CONTENTS

Director’s Message

2003 was a positive year for the laboratory. All of our research seemed to have a boost in productivity during 2003, with strong research activity and good output of publications. We are looking forward to another good year in 2004.

Francis Nakayama retired during 2003, although it is hard to tell because he comes to work nearly every day, is still active writing grants, and has maintained his enthusiasm for his research. There is little evidence that he has started winding down.

In October, Norma Duran accepted a position with the Environmental Protection Agency in El Paso, Texas. We wish her well and know she will do good work for the EPA in their border issues with Mexico. Norma still visits the lab and interacts with some of her students who stayed to finalize some of the research started while Norma was still here.

The CRIS project for new crops research was approved through the Office of Scientific Quality and Review (OSQR) during 2003. This was an extensive peer review process. This group has charted a new course for the next 5 years which will lay the groundwork for an exciting future for this area of research. They are to be congratulated for their strong planning effort.

The final design for the new facility at Maricopa was completed during FY2003. I’m sure the laboratory staff is relieved to have that step behind them, as they all spent a considerable amount of time over the last three years with The Smith Group, the A&E firm who designed the new research center. The contract is expected to be awarded during early 2004.

Pernell Tomasi joined the lab as a permanent category 3 scientist during 2003. Pernell has worked at the lab for over ten years as a student and technician, and has demonstrated his research capabilities with tissue and ovule culture techniques for interspecific hybrids.

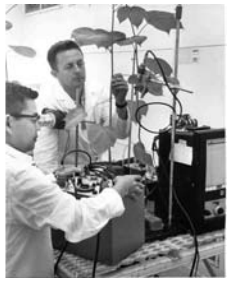
Andrew Salywon was hired as a post-doc (category 2 scientist) to conduct work finding molecular makers to assist in constructing a genetic map, and for selection in breeding. Andrew received his PhD from Arizona State University in Plant Biology this year and has worked at our lab in the past on plant collection explorations.

Andrew French was chosen to fill the remote-sensing position vacated by Ed Barnes. Andrew will report some time in the Spring of 2004.

Three positions were filled in the Administrative Office at our location. . Eiko Adkisson was hired as Administrative Officer. She came to us from the National Park Service where she handled administrative duties for The Grand Canyon National Park. Eiko in turn hired Annette McNeeley from the Department of Defense as the budget and accounting clerk and Regan Alexander from Western Cotton Research Lab as our purchasing agent. Welcome aboard Eiko, Annette, and Regan.

Bert Clemmens
Laboratory Director

Dedication



Dr. Nakayama retired in January 2003 after working as an ARS Research Chemist for 40 years, including five years as a Research Leader. He now serves as a Laboratory Collaborator.

His interests in broad areas of scientific endeavor benefited agriculture in many ways. He contributed theoretical concepts and simplified laboratory procedures for determining the ability to treat various soils to seal canals and ponds. Ranchers have used these procedures for reducing seepage in stock ponds.

He developed guidelines on irrigation water treatment for the prevention of clogging of drip irrigation systems, which also includes the evaluation of irrigation water for its suitability in drip systems. Chemical water treatments based on these findings are now accepted and used as routine procedure by drip irrigation operators. Users' manuals for farm operators and designers now include water treatment recommendations for setting up and maintaining drip/trickle irrigation systems.

He was a major contributor to a team that worked toward the commercialization of various lines of guayule, a North American Desert plant of major interest to the United States as a source of latex rubber that did not depend on foreign imports.

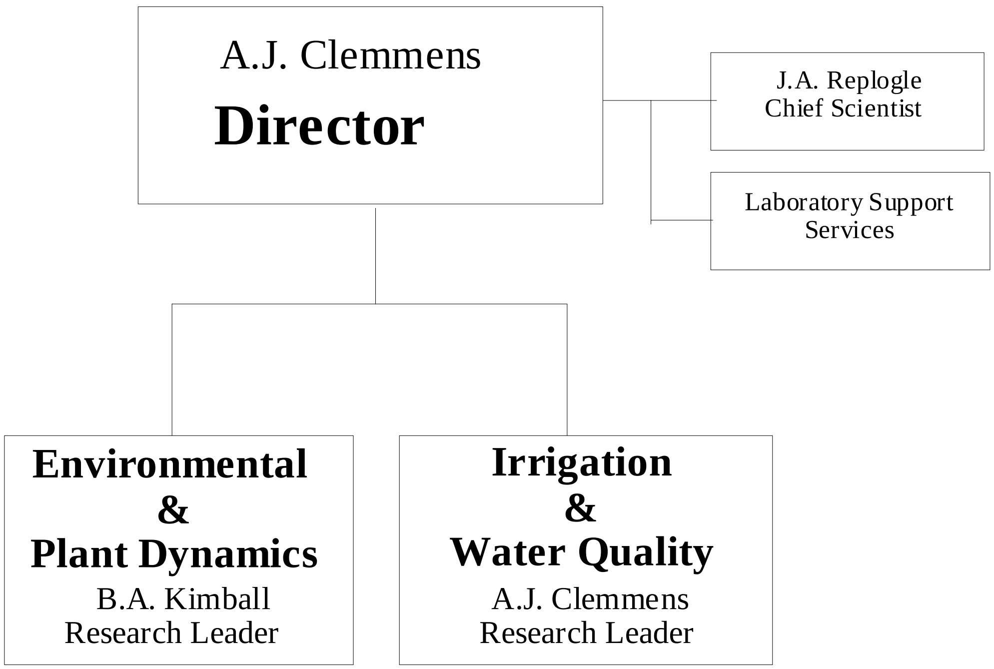
He was a major participant of another team that developed information for the agronomic and water management of guayule that includes planting, maintenance, and harvesting of the crop. Adequate information is now available for the commercial production of guayule in the southwestern United States. The drought tolerant guayule can be handled as a temperate zone plant similar to cotton, but management has the flexibility of delaying or skipping an irrigation without killing the plant.

He developed the idea of using a byproduct of the latex extraction, guayule resin, for controlling termites and fungal wood rot to both solve the problem of wood damage, and to solve the waste problem of guayule by-products, when latex production is fully commercialized, by incorporating the byproducts onto wood composite materials. This resulted in the granting of a patent on which he is the senior named patent holder. This promises to produce tremendous savings to the consumer and conserve the country's wood resources, which otherwise would be required for the replacement of termite- and fungi-damaged wood.

Over this period, he was senior author or coauthor of 129 journal articles and technical publications, and senior-author of five book chapters, coauthor of four other book chapters, wrote five book reviews, and edited one book as a senior editor, as well as producing numerous editorials, abstracts, research reports, and popular articles. He was instrumental in contributing to the establishment of an international journal, Industrial Crops and Products, and has been the original Editor-in-Chief since 1991, following editorships of the El Guayulero Newsletter and the Association for the Advancement of Industrial Crops Journal.

Laboratory Program

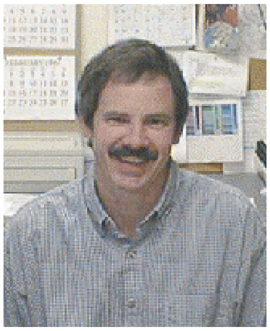
Laboratory Organization



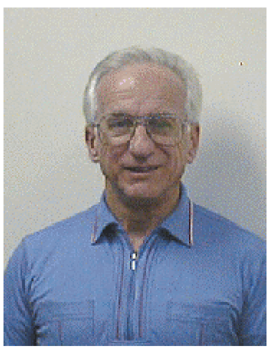
Mission

The mission of the U. S. Water Conservation Laboratory (USWCL) is to conserve water and protect water quality in systems involving soil, aquifers, plants, and the atmosphere. Research thrusts involve developing more efficient irrigation systems, improving the management of irrigation systems, developing better methods for scheduling irrigations, developing the use of remote sensing techniques and technology, protecting groundwater from agricultural chemicals, commercializing new industrial crops, and predicting the effect of future increases of atmospheric CO_2 on climate and on yields and water requirements of agricultural crops.

LABORATORY MANAGEMENT



ALBERT J. CLEMMENS, B.S., M.S., Ph.D., P.E., Laboratory Director, Research Leader for Irrigation and Water Quality, and Supervisory Research Hydraulic Engineer
Surface irrigation system modeling, design, evaluation, and operations; flow measurement in irrigation canals; irrigation water delivery system structures, operations management, and automation.



JOHN A. REPLOGLE, B.S., M.S., Ph.D., P.E., Chief Scientist and Research Hydraulic Engineer
Flow measurement in open channels and pipelines for irrigation; irrigation water delivery system structures, operations, and management.

BRUCE A. KIMBALL, B.S., M.S., Ph.D., Research Leader for Environmental and Plant Dynamics and Supervisory Soil Scientist
Effects of increasing atmospheric CO_2 and changing climate variables on crop growth and water use; free-air CO_2 enrichment (FACE) and CO_2 open-top chambers and greenhouses; micrometeorology and energy balance; plant growth modeling.

LABORATORY SUPPORT SERVICES

ELECTRONICS ENGINEERING LABORATORY

D.E. Pettit, Electronics Engineer

The electronics engineering laboratory is staffed by an electronics engineer whose duties include design, development, evaluation, and calibration of electronic prototypes in support of U.S. Water Conservation Laboratory research projects. Other responsibilities include repairing and modifying electronic equipment and advising staff scientists and engineers in the selection, purchase, and upgrade of electronic equipment. Following are examples of work performed in 2003:

- Evaluated a soil moisture probe that uses fiber optics by Alessi and Lyle Prunty for a possible project with Floyd Adamsen. Also consulted with John Replogle on a 24 cm depth gage transducer that would be portable for field use.
- Evaluated and advised Bruce Kimball on interfacing a control unit between his infrared heater units the data loggers.
- Assisted Neal Adam in the design abilities and methods used for his seed germination project using thermal piles versus hot-water bath methods.
- Redesigned the interface for three Xerox SPAD meters connecting to Palm PDA for Paul Pinter's field measurement studies.
- Designed and constructed 8 ten-channel PH probe amplifier boards using surface mount technology for Floyd Adamensen's and Clint William's Trace Rios project.
- Designed and constructed a DC to DC converter and installed a switch control to provide power to the three enclosed units for Floyd Adamsen's flow controller.
- Continued design of hardware and software for the GEN III probe utilizing a surface-mount microcontroller that is flash programmable and interfaceable to a new 24-cm variable water detection transducer.
- Redesigned the 24-cm low-power optics source/detector transducer using surface mount technologies to interface to the GEN III probe. Experimented with several optic parts for variable water level detection.
- Continued designing schematic capture parts and circuit board footprints for the appropriate ORCAD libraries.
- Continued repairs on LPKF circuit board mill machine and updated the hardware.
- Repairs accomplished: centrifuge CR 412, thermostat and temperature sensors and precision of them, spectrophotometer 480 LC, and vehicle trailer wiring.

LIBRARY AND PUBLICATIONS

Selina McCain, Publications Clerk, and Thelma Lou Draper, EPD Secretary

Library and publications functions, performed by one publications clerk, include maintenance of records and files for publications authored by the Laboratory Research Staff, and publications co-authored with outside researchers, as well as holdings of professional journals and other incoming media. Support includes searches for requested publications and materials for the staff. Library holdings include approximately 2600 volumes in various scientific fields related to agriculture. Holdings of some professional journals extend back to 1959.

The U.S. Water Conservation Laboratory List of Publications, containing over 2400 entries, is maintained on ProCite, an automated bibliographic program. The automated system provides for sorting and printing selected lists of Laboratory publications and is now accessible on LAN by the Research Staff and on the USWCL home page (www.uswcl.ars.ag.gov) by the public. Publications lists and most of the publications listed therein are available on request.

We are in the process of converting publications into pdf files which will allow easy access to our lab publications through our home page on the web. There are currently approximately 300 publications available for public use.

COMPUTER FACILITY

T.A. Mills, Computer Specialist

The computer facility is staffed by one full-time Computer Specialist and one full-time Computer Assistant. Support is provided to the ARS Phoenix Location, including the U.S. Water Conservation Laboratory (USWCL), the Phoenix Location Administration Office, and the Western Cotton Research Center (WCRL).

The facility is responsible for designing, recommending, purchasing, installing, configuring, upgrading, and maintaining the Phoenix Location's Local and Wide Area Networks (LAN, WAN), computers, and peripherals. The USWCL LAN consist of multiple segments of 10 Base-T, 100 Base-T, 1 Gigabit hubs and switches. The LAN is segmented using high speed switches. Segments are made up of fiber optics, CAT 5. This configuration currently provides over 200 ports to six USWCL buildings in addition to 48 ports at WCRL. Internet service is provided by Arizona State University (ASU) via a Point-to-Point T-1 line. The facility maintains two Internet domains uswcl.ars.ag.gov, and wcrl.ars.usda.gov. The Laboratory LAN is comprised of several servers operating under Windows NT 4.0 and Windows 2000. End users operate under Windows 2000, and Windows NT 4.0 with a fewWindows 9x and XP workstations. LAN security is enhanced by Cisco PIX firewall and three routers implemented in the LAN.

Services such as print, file, remote access, and backup are provided by the USWCL LAN. Other services such as DNS and E-Mail are provided to both the USWCL and WCRL. The USWCL maintains Web Servers for both USWCL (www.uswcl.ars.ag.gov) and WCRL (www.wcrl.ars.usda.gov). Currently FTP access is restricted to local accounts. This policy may be relaxed during the coming year.

MACHINE SHOP

“Skip” Eshelman, Physical Science Technician

The machine shop provides facilities to fabricate, assemble, modify, and replace experimental equipment in support of U.S. Water Conservation Laboratory research projects. Trathford “Skip” Eshelman monitors the shop and provides assistance to laboratory personnel in the use of shop equipment. The following are examples of work orders completed in 2003:

- Built a narrow and a 4-ft wide sampler rack for test as a water flow-measuring device.
- Constructed sampling devices for use in water treatment ponds at Tres Rios.
- Made solar panel frames.
- Designed and assembled trailer for use in the field with 4 track vehicle.
- Built an adjustable bracket to hold sensors to wheeled linear.
- Performed repair and maintenance on injector pumps.
- Constructed table for soil grinder.
- Painted rebar ruler stakes.
- Made reference panels for different white color readings.
- Constructed new drip pans for coolers on the large greenhouse.
- Fabricated weatherproof enclosures for data loggers.
- Milled airborne multiple camera platform.
- Made brackets for mounting sensors on stand pipes.
- Built temperature gradient table.

USWCL OUTREACH ACTIVITIES

The USWCL staff participates in numerous activities to inform the public about ARS and USWCL research, to solicit input to help guide the USWCL research program, to foster cooperative research, and to promote careers in science.

The Science Open House Water & Science Ag-Ventures, February 25-26. The event was held at the University of Arizona, Maricopa Agricultural Center, and targeted high school and junior high school students encouraging them to seek science careers. Some charter schools with agricultural interests also attended. Five displays and presentations were included, four from the USWCL and one from the Western Cotton Research Lab (WCRL). Glenn Fitzgerald and Tom Clarke presented "Remote Sensing Tools," Gail Dahlquist and Terry Coffelt presented "New Crops and New Products," Norma Duran presented "Wastewater," and Jackie Blackmer from WCRL presented "Insect Communication."

Visit by Mexican Students, March 5. Students from the seventh-year irrigation class of the Universidad Autonoma Chapingo, Chapingo, Mexico, visited the laboratory. John Replogle presented an overview of our laboratory and discussed current programs and gave them a tour of the hydraulics laboratory, which featured recent innovations involving flumes, Ventury meters, pitot tubes, flap-gate studies and the modification of velocity profiles in pipes to improve flow meter performance and accuracy. John also presented current research on open-channel and pipe flow measurement. Theodor Strelkoff discussed current research on surface irrigation modeling.

SAFETY

T. Steele

The Laboratory Safety Committee enjoys well-deserved respect from the employees. It is a time-consuming commitment and requires judicious management of time and work priorities. Serving on the safety committee, however, is gratifying in terms of its record of accomplishments. A few examples of our accomplishments follow:

1. In preparation for vacating the facility when the Location consolidates and relocates to the Maricopa Agricultural Center (MAC) a Phase I Environmental Site Assessment SOW was developed and the contract awarded. The final report has been delivered and a proposal for Phase II is in progress.

2. Both the Nuclear Regulatory Commission and the USDA Radiation Safety Staff conducted inspections of our Radiation Program during the year and no violations were noted by either group.

3. A Location Continuity of Mission Plan was developed and disseminated. The plan outlines essential decision-making personnel, mission critical assets that require protection and the specific employees that are delegated responsibilities for executing the plan.

4. The location has been able to maintain its conditionally exempt small quantity generator status by careful review of process start materials and subsequent waste generation.

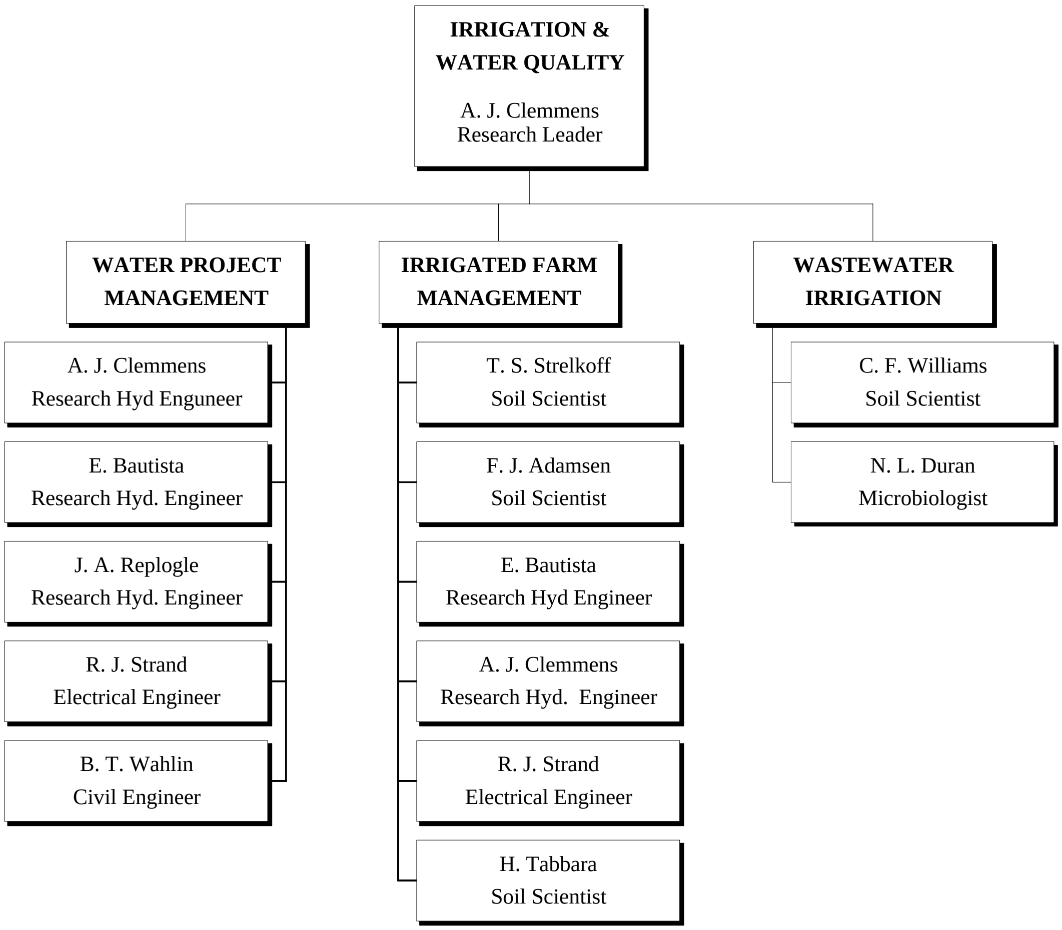
Employees are encouraged to report all safety concerns, even those that might seem trivial.

The committee takes its duties seriously and has worked diligently to insure compliance with all EPA and OSHA regulations and radiological safety protocols.

The location staff thanks the committee for their good work on our behalf and looks forward to another year of safety awareness and exemplary records.

IRRIGATION
&
WATER QUALITY
MANAGEMENT UNIT

I&WQ Organization



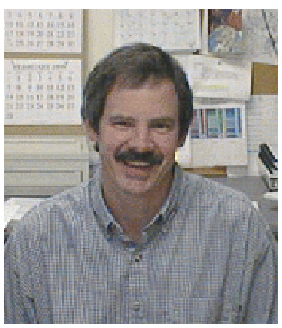
Mission

The mission of the Irrigation and Water Quality (I&WQ) Research Unit is to develop management strategies for the efficient use of water and the protection of groundwater quality in irrigated agriculture. The unit addresses high priority research needs for ARS's National Programs in the area of Natural Resources & Sustainable Agricultural Systems. The unit primarily addresses the Water Quality and Management National Program. It also addresses the application of advanced technology to irrigated agriculture.

I&WQ RESEARCH STAFF

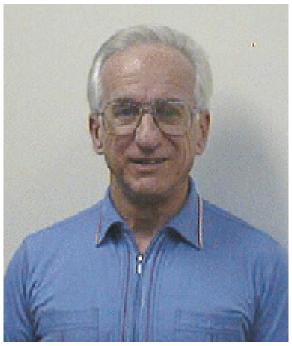
FLOYD J. ADAMSEN, B.S., M.S., Ph.D., Soil Scientist
Management practices that reduce nitrate contamination of groundwater while maintaining crop productivity; application of 100% irrigation efficiency; winter crops for the irrigated Southwest that can be double-cropped with cotton; contributions of natural and urban systems to nitrate in groundwater.

EDUARDO BAUTISTA, B.S., M.S., Ph.D., Research Hydraulic Engineer
On-farm irrigation system hydraulic modeling; hydraulic modeling of irrigation delivery and distribution systems; control systems for delivery and distribution systems; effect of the performance of water delivery and distribution systems on-farm water management practices and water-use efficiency; integrated resource management and organizational development for irrigated agricultural systems.



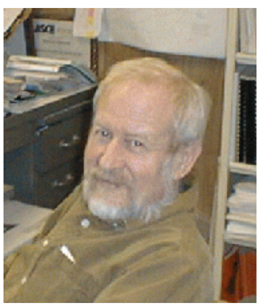
ALBERT J. CLEMMENS, B.S., M.S., Ph.D., P.E., Laboratory Director, Research Leader for Irrigation and Water Quality, and Supervisory Research Hydraulic Engineer
Surface irrigation system modeling, design, evaluation, and operations; flow measurement in irrigation canals; irrigation water delivery system structures, operations management, and automation.

NORMA L. DURAN, B.S., Ph.D., Microbiologist
Wastewater irrigation; molecular detection of waterborne pathogens; pathogen regrowth and disinfectant by-product formation in distribution systems; fate and transport of pathogens in the subsurface environment.



JOHN A. REPLOGLE, B.S., M.S., Ph.D., P.E., Chief Scientist and Research Hydraulic Engineer
Flow measurement in open channels and pipelines for irrigation; irrigation water delivery system structures, operations, and management.

ROBERT J. STRAND, B.S., Electrical Engineer
Automatic control of irrigation delivery systems; development and integration of field sensors, intelligent field hardware, USWCL feedback and feedforward control software, and commercial supervisory control software to create a plug-and-play control system.



THEODOR S. STRELKOFF, B.C.E., M.S., Ph.D., Research Hydraulic Engineer
Surface-irrigation modeling: borders, furrows, two-dimensional basins; erosion and deposition; design and management of surface-irrigation systems; canal-control hydraulics; flood-routing methodologies; dam-break floodwaves; flow in hydraulic structures.

BRIAN T. WAHLIN, B.S., M.S., Civil Engineer
Flow measurement in open channels and pipelines for irrigation; irrigation water delivery system structures, operations, and management.

CLINTON WILLIAMS, B.S., M.S., Ph.D., Soil Scientist

Wastewater irrigation and water reuse; fate and transport of organic and inorganic contaminants found in treated sewage effluent and biosolids in soil systems; development of irrigation practices that protect ground and surface water quality; develop safe and effective irrigation practices using treated sewage effluent.

MANAGEMENT
OF
WATER SUPPLIES
FOR
IRRIGATION

Albert J. Clemmens, Research Hydraulic Engineer
John A. Replogle, Research Hydraulic Engineer
Eduardo Bautista, Research Hydraulic Engineer
Robert J. Strand, Electrical Engineer
Brian T. Wahlin, Civil Engineer

PROJECT SUMMARY

Water supplies are limited in many areas of the country, particularly in the arid west where irrigated agriculture is the largest user of fresh water. Expanding urban populations and environmental water needs will potentially reduce water available for irrigation in the future. Water users are faced with requirements to more accurately document water uses and return flows. Water measurement and control in irrigated agriculture has experienced significant advances over the last two decades, yet further advancement is both possible and needed. Under this research project, we intend to develop improved water measurement technology, improved water accounting methods, and improved water control technology. New measurement methods will be developed for steep, sediment laden channels, channels with little or no head available, low-head pipelines (culverts), and submerged radial gates. A new canal automation system will be released to a CRADA partner to provide greater water control and operational flexibility to meet user needs. Water balance methods will be further developed to assist water purveyors with documenting water use, including methods to determine sources of error, which indicate where measurement effort should be focused.

OBJECTIVES

1. Flow Measurement and Accounting: We will develop a series of improvements to existing methods for measuring water flow rates and volumes in rivers, streams, canals, and culverts (low pressure or not flowing full). A series of laboratory studies is planned for currently identified water measurement problems (see research approach). We will continue to support software developed for design and calibration of long-throated flumes, will cooperate with customers to evaluate their water measurement and accounting methods, and will work toward solutions to their flow measurement problems.

2. Water Control: We will develop a series of methods, hardware, and software for improving the control of water in open-channel distribution systems typical of irrigation projects or large water supply projects. A new canal automation system currently under development will be turned over to our CRADA partner. The mechanical/hydraulic controller (DACL), used to maintain constant flow rates at canal offtakes, will be improved to make it more usable in remote sites.

NEED FOR RESEARCH

Description of Problem to be Solved

Competition for limited water resources among various users is increasing in many areas of the country, but particularly in the arid west. Irrigated agriculture is the largest user of fresh water resources and, thus, it needs to improve its water management (CAST 1996, National Research Council 1996). Important elements for improving agricultural water management are improved measurement, control, and ultimately, accountability of water resources at the irrigation project level. Water uses at the project or hydrologic unit scale are often poorly documented making meaningful management of water supplies difficult. Also, water supplies for agriculture from large irrigation projects are often not controlled well, resulting in over-delivery to individual users and ineffective use at the farm level. As water moves downstream through various projects and uses, its quality degrades as salts, trace metals, and other contaminants are concentrated, often to the point of being unusable or having a negative impact on the environment. The objectives of this project are to develop tools for improving the management of water supplies, particularly for irrigation.

Relevance to ARS National Program Action Plan

The research is part of National Program 201, Water Quality and Management. The project falls under Component 2, Irrigation and Drainage Management. Both objectives deal with agricultural water conservation and fit under Problem Area 2.3 (Water Conservation Management), Goal 2.3.1 (Water Conservation Technologies). The research also supports Goal 2.3.3 (Agricultural Water Conservation and Environmental Quality).

Potential benefits

Large-scale water supplies will be better managed in arid regions with the tools developed here. Water measurement, accounting, and control will be improved in irrigated agriculture, supporting more rational analysis of the impact of irrigated agriculture on the environment and allowing more rational decisions by society about water allocation and use.

Anticipated Products

New technology is provided for improving the operation and management of water projects, including canal automation/control and water measurement/accounting technology.

Customers of the research and their involvement

Based on past successful technology transfer and the anticipated products, customers will include the U.S. Bureau of Reclamation (USBR), Natural Resources Conservation Service, U.S. Geological Survey, Army Corp of Engineers, Bureau of Indian Affairs, State Departments of Water Resources (particularly Arizona and California), land-grant universities, civil and agricultural consulting engineers, and water purveyors (water conservancy districts, irrigation districts, municipalities, etc.). We have cooperated with NRCS staff on the application of flow measurement technology and related research needs at all levels (field office to national) and in states across all regions of the country. Our main point of contact is Tom Spofford, Water and Climate Center, Portland OR (letter attached), who disseminates information widely within NRCS. With USBR, cooperation on water measurement and control has been mainly with the Water Resources Research Lab, Denver CO (Cliff Pugh, letter attached). They transfer our technology to regional and area offices through manuals and technical assistance programs. Research on water-balance methods has primarily been with the Lower Colorado Region of USBR (Steve Jones), who along with other regions are transferring this technology to water purveyors through their water conservation plans. Further planned activities with Paul Matuska (letter attached) are expected to have additional impact on water conservation plans. Several water purveyors (e.g., Salt River Project, Maricopa Stanfield I&D District, Imperial Irrigation District) have been directly involved in various studies and technology transfer activities since much of this research must be conducted within real, full-size water systems. Water meter, remote monitoring, and hydrologic instrumentation manufacturers have been customers, who are expected to continue with this project (e.g., Automata, Global Water, Micrometer, Nu-Way Flume Co., Plastifab, etc.). Individual water users also will be customers, particularly for the water measurement devices.

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

Expected outcomes include: (1) improved water measurement devices, (2) new canal automation technology, and (3) improved water use assessment methods and performance indicators.

Milestone Timeline

Research Component	end of year 1	end of year 2	end of year 3	End of year 4	end of year 5
Water Measurement and Accounting	Lab study on flow conditioning for pipes/culverts completed (Replogle)	Lab study on debris-shedding propeller meter completed (Replogle)	Field studies on surface-velocity-based method completed (Replogle)	Lab study on high sediment load flume completed (Replogle)	
		Laboratory studies on submerged radial gates completed (Clemmens)	Verification of radial gate calibration method completed (Clemmens)		Field study on water balance accuracy completed (Clemmens)
Water Control	Initial version of canal automation system turned over to CRADA partner (Clemmens)	Improved interface for canal automation system provided to CRADA partner (Clemmens/Bautista)	Final version of canal automation technology given to CRADA partner (Clemmens)		New DACL control system developed and lab testing completed (Replogle)
		Field studies of canal automation on steep canal (WM at MSIDD) completed (Clemmens)	Field application of feedforward routing method completed (Bautista)		Field studies of canal automation on canal with mild slope complete (Clemmens)
	Feedback control method for branching canals developed and simulation testing completed (Clemmens)	Simulation testing of Model Predictive Control for branching canal completed (Clemmens)		Upstream control method developed and simulation testing completed (Clemmens)	

PROGRESS

Many water delivery systems do not provide water to users at the proper time and rate of flow, resulting in water losses and decreased production. The Canal Automation Team at the U.S. Water Conservation Laboratory developed a water demand scheduling program, called SacMan Order, to help water districts manage water demands and to route changes in demand through their canal system. SacMan Order, a part of Software for Automated Canal Management or SacMan, is a computer program that accumulates water orders, keeps track of demand at any point in the system,and determines when water needs to be released from each gate structure in order to get the right amount of water to the right place at the right time. This software developed in cooperation with a CRADA partner could significantly improve the ability of canal operators to satisfy customer demands, thereby improving the efficiency of water use.

The automatic control of canals, while providing significant potential for improving water management in the west, has found little application, at least partly because existing automation schemes only consider a single in-line canal and thus do not provide control for the entire canal network. Engineers at the U.S. Water Conservation Laboratory developed a new automation scheme that can be applied to an entire canal network. The theory for control of canal networks was demonstrated through computer simulation for a majority of the canal system of the Salt River project. It demonstrated that such controls are both possible and can lead to improved canal operations, thereby improving the service to water users and potentially increasing their water use efficiency.

Methods currently in use to automate the operation of canal systems are based on simple control logic that is not always well suited for complex water distribution systems. A more flexible automatic control system, Model Predictive Control or MPC, was demonstrated at the U.S. Water Conservation Lab. to provide control at least as good as other methods, but with increased ability to handle real-world constraints. Simulation studies on the test canal of the American Society of Civil Engineers and on the Salt River Project canal network demonstrated that MPC was at least as effective as optimal control methods. The ability of MPC to handle real-world constraints will increase the likelihood of success for canal automation schemes at improving water management in the west.

Water released from the head of the canal arrives at the downstream end gradually and often over a time that is difficult to predict, thereby complicating the delivery of water to users. A comprehensive analysis of wave travel in canal by the canal automation team at the U.S. Water Conservation Lab. demonstrated that volume compensation approaches provided control as good as more complex methods. The automation team developed and verified through computer simulation that properly accounting for the volume changes in a canal pool was more important for canal control than accurately estimating wave travel times. This approach greatly simplifies the method for scheduling demand changes for a canal and should make such approaches more acceptable to canal operators.

Irrigation expansion and groundwater decline in the lower Mississippi River Valley has prompted water users to explore alternative water sources, including diversion of water from environmentally sensitive rivers. A study of water use by irrigated agriculture at a watershed
scale was conducted by the Arkansas Natural Resources Conservation Service (NRCS) and the U.S. Water Conservation Laboratory. This study demonstrated that the on-farm improvement planned by the NRCS, including storage reservoirs, tailwater pits, pipelines and booster pumps, could reduce the need for external water sources by more than 1/2 through the capture of rainfall runoff and irrigation tailwater, and that the overall irrigation efficiency is relatively insensitive to individual field application efficiency. This study demonstrates the importance of irrigation infrastructure in the humid south and their impact on reducing water diversions and groundwater pumping.

Laboratory studies on flow conditioning in pipes and culvert is continuing. The methodology for measuring velocity distributions is working, and the large 30" concrete pipe has been set up to handle the variety of tests planned. Some of the equipment for the field study extension to determine errors in flow meter installations has been purchased and is being evaluated.

The main features of the SacMan canal automation software have been field tested at the Maricopa Stanfield Irrigation and Drainage District. An initial version of the software, handling manual control systems, was turned over to our CRADA partner. The control system has been installed at the Central Arizona Irrigation and Drainage District, Eloy, AZ. The initial installation has manual control, with full automatic control being phased in over the next few years. The first full version of the software will be provided in late FY03 or early FY04.

Through cooperation with the Bureau of Reclamation, Water Resources Management Lab, we were able to analyze the data collected on radial gates by the Bureau in the early 1980s. This data supported our approach in calibrating submerged radial gates, but also showed that a wider range of data is needed to provide useful calibration. Preliminary field studies at the Salt River Project also supported our approach. In FY03, we installed brackets during canal dry-up so that we could measure the pressure below the gate at the experimental site on the Salt River Project's Arizona Canal.

NEW RADIAL GATE DESIGN
New radial-gate designs for irrigation canals relocate the gate pivots above a canal bottom seal so that the gate can swing through the bottom location and serve either as an overflow weir or as a traditional underflow orifice. The prototype gate appears fully capable of meeting operational requirements related to controlling and measuring flow rates over an extended flow range involving either overshot (weir) or undershot (orifice) modes in a restricted width that would challenge previous radial gate structures. Both floating and bed-load trash are readily handled by the dual modes of operation. Special operational procedures for trash handling are offered when two gates can be operated in opposite modes at the same time.

DESIGNING A TOTAL-LOAD, STREAM-FLOW SAMPLER

Total-load stream flow sampling has been a perpetual problem in sediment monitoring to document erosion into reservoirs and evaluate watershed treatments. This is particularly important with the recent history of major forest fires. Usually a combination of bed-load sampling devices, suspended-load suction samplers, and a flume for total flow rate, are used. A total-load sediment sampler designed on a new and simplified concept performs all three of these functions well. It requires installation in sites that can provide an over-fall height greater than the maximum stream flow depth. Design parameters are offered to allow flow accuracies to within 3%, including unbiased sediment size distributions, a major problem with previous sampling systems.

Publications:

Bautista, E., Strelkoff, T.S., Clemmens, A.J. General characteristics of solutions to the open-channel flow feedforward control problem. Journal of Irrigation and Drainage Engineering. 2003. v 129(2):129-137.

Wahlin, B.T. Clemmens, A.J. Performance of historic downstream canal control algorithms on ASCE Test Canal 1. Journal of Irrigation and Drainage Engineering. 2002. v 128(6): 365-375.

Replogle, J.A., Adler, R., R.S. Gooch. Operational evaluations of new radial gate design. Proceedings of 2nd Int. Conference on Irrig. & Drain.2003. p. 421-433.

Wahlin, B.T., E. Bautista. Feedforward control: volume compensation versus model predictive control. Proceedings of 2nd Int. Conference on Irrig. & Drain. 2003. p. 487-496.

Clemmens, A.J., Strand, R.J., Feuer, L. Application of canal automation in central Arizona. Proceedings of 2nd Int. Conference on Irrig. & Drain. 2003. p. 455-464.

Wahl, T.L., Clemmens, A.J., Replogle, J.A. The energy correction for calibration of submerged radial gates. Proceedings of 2nd Int. Conference on Irrig. & Drain. 2003. p. 757-766.

Robinson, P., Clemmens, A.J., Carman, D.K., Dalmut, Z., Fortner, T. Irrigation development in eastern Arkansas: water supplies, uses, and efficiencies. Proceedings of 2nd Int. Conference on Irrig. & Drain. 2003. p. 283-292.

Clemmens, A.J., Replogle, J.A. Irrigation metering. Encyclopedia of Water Science. 2003. p. 495-497.

Clemmens, A.J. Canal automation. Encyclopedia of Water Science. 2003. p. 53-56.

ASSESSMENT AND CONTROL OF PATHOGENS IN MUNICIPAL WASTEWATER USED FOR IRRIGATION TO PROTECT CROPS AND GROUNDWATER

Norma L. Duran, Microbiologist

PROJECT SUMMARY

Population growth and water shortages will increase the need to use treated wastewater effluent for irrigation, particularly in areas where fresh water resources are limited. However, there are serious concerns about the transmission of pathogens and toxic chemicals from municipal and animal wastewater to agricultural land and crops and thus to human food and to groundwater. An increase in foodborne disease in the U.S. has been attributed in part to the transmission of pathogens in the water used for irrigation of edible crops. Furthermore, there is limited knowledge on the long-term effects of irrigation with sewage effluent on soil and underlying groundwater. Thus, the aim of this research project is to assess the microbiological safety of waste water irrigation of food crops and potential environmental hazards in order to protect the public health and our future groundwater resources. Molecular biology techniques will be used to evaluate pathogen survival, regrowth, and transport in vegetated and non-vegetated soil columns, water distribution systems, and field sites with a long history of wastewater application for crop irrigation. Studies will determine the movement of pathogens through the soil column as well as the factors affecting their survival and transport. This could lead to the development of management strategies that would minimize the introduction of pathogens into the environment and thus reduce the risk to human health.

OBJECTIVES

1. Determine the fate and transport of pathogens present in treated sewage using vegetated (grass and alfalfa) and non-vegetated soil columns irrigated at various efficiencies or flooded to simulate artificial groundwater recharge conditions with chlorinated secondary sewage effluent. The columns will also be used to determine the fate of organic compounds, such as pharmaceuticals and pharmaceutically active chemicals and disinfection by products under a companion project under National Program 201, Water Quality and Management (Wastewater Irrigation and Groundwater Recharge).

2. Determine if wastewater irrigation has an effect on groundwater quality by analyzing upper groundwater samples below agricultural fields, urban irrigated areas (golf courses, parks, landscaping), and/or groundwater recharge areas with a long history of municipal wastewater application for emerging microbial pathogens including but not limited to *Escherichia coli* O157:H7, *Salmonella*, and *Campylobacter.* The samples will also be analyzed for pharmaceuticals and other chemicals under a companion project.

3. Determine if bacterial pathogens present in treated sewage can regrow in conveyance systems used to transport wastewater to fields for irrigation of fresh fruits and vegetables and conduct laboratory studies using a model system to determine the physical and chemical factors that promote/inhibit pathogen regrowth so that cost effective prevention strategies can be developed.

NEED FOR RESEARCH

Description of the problem to be solved

Increasing populations, finite water resources and increasingly stringent treatment requirements for discharge of sewage effluent into surface water is increasing the need for water reuse practices in the United States. However, due to recent foodborne outbreaks, public concern about the potential human health risks and environmental consequences of water reuse in agriculture is increasing. Thus, research is needed to increase our current knowledge on the long-term effects of wastewater irrigation on food, soil and underlying groundwater. In addition, the potential for pathogen regrowth in conveyance systems used to transport treated wastewater over long distances to the irrigated areas also deserves attention. Furthermore, proper assessment of water reuse practices will require microbial detection methods that are fast, sensitive and specific for pathogens of concern. Addressing these research needs will help assess the environmental and public health risks associated with wastewater irrigation so that future problems of food, soil and groundwater contamination can be anticipated or avoided.

Relevance to ARS National Program Action Plan

The research directly addresses national and global problems dealing with safety of food produced in fields that have been irrigated with treated sewage effluent or with effluent contaminated water. This project falls under National Program 108, Food Safety, Microbial Pathogens Component. The reduction of microbial pathogens in food products also relates to reducing environmental contamination from animal (and human) waste. This project is related to objective 1.6.1.1 "Identify sources and reservoirs of pathogens relative to on-farm and environmental situations" by determining the fate of pathogens in wastewater applied as irrigation to crops.

Potential benefits

Benefits from attaining the objectives include safe use of sewage effluents for irrigation from the standpoint of food safety and groundwater protection. Water reuse will be more common and the practices will be safer for public health.

Anticipated products of the research

Anticipated products of the research include (1) improved techniques of sewage treatment and system management for safe and sustainable water reuse with minimum adverse health effects and in environmentally acceptable ways, and (2) new guidelines for irrigation with wastewater to protect groundwater and surface water quality and for control measures of pathogen regrowth in water distribution systems.

Customers of the research and their involvement

Customers of the research include the public, farmers and farm workers, water planners and managers, government regulators, consulting engineers, water districts and municipalities, wastewater treatment plant operators and water managers.

SCIENTIFIC BACKGROUND: Refer to 2002 Annual Report

APPROACH AND PROCEDURES: Refer to 2002 Annual Report

PHYSICAL AND HUMAN RESOURCES: Refer to 2002 Annual Report

MILESTONES AND OUTCOMES

By the end of FY2002, the initial screening of pathogens in sewage and column effluents will be completed and should determine the presence of specific pathogens of highest concern to groundwater contamination. By the end of FY2003, we expect results regarding the fate and transport of pathogens from field studies as well as the completion of pathogen regrowth assessment in distribution systems. Studies on the effects of irrigation and groundwater recharge with sewage effluent will continue until dynamic equilibrium or end conditions are reached. If adverse effects are observed, procedures for mitigating these effects will be developed and tested on the columns by FY2004 (Table 5).

Table 5. Milestones and outcomes

Research Study-Component	**Months of Study**			
	11	22	33	44
Pathogen Transport/ Column Studies	Operation and management for irrigation and groundwater recharge procedures, development of sampling and DNA extraction protocols completed	Operation continued, establish PCR procedures for selected pathogens, initial screening of pathogens going into and out of the columns completed	Operation continued, evaluation of fate and transport of pathogens completed	Final reports and manuscript prepared, develop recommendations and future studies
Pathogen Transport/ Field Studies	Site characterization and sample collection completed	Optimization of DNA extraction and analysis protocols completed	Detail sampling to valuate fate of selected pathogen(s), analysis by PCR completed	Interpretation of results, final reports and manuscript prepared, develop recommendations for future studies
Pathogen Regrowth/ Laboratory and Field Studies	Field site characterization, operation and management of annular reactor completed	Operation and sampling of annular reactor continued, sampling at different points in the water distribution completed	Molecular analysis of samples completed	Interpretation of results, final reports and manuscript prepared, develop recommendations for the control of pathogen regrowth

PROGRESS:

SOIL COLUMNS

Laboratory studies have been accomplished using soil column in collaboration with the USGS to identify the organic wastewater contaminants including pharmaceuticals and pathogens that can persist under groundwater recharge conditions. The results from this study have led to an additional project involving the testing of microbial resistance to the antibiotics, which were identified to persist in the soil column studies during recharge. This project is in collaboration with the USGS and the ARS Food and Feed Safety Research Unit. The information obtained from this study will help evaluate the degree by which water reuse practices will influence the transmission of antimicrobial resistance determinants to groundwater when wastewater is used for irrigation and/or groundwater recharge.

FIELD STUDIES

Field studies are in progress to study impacts of land application of wastewater on groundwater quality. A project was initiated in collaboration with the USGS to study the spatial and temporal distributions of wastewater contaminants in the surface water and in the underlying groundwater at an effluent-dependent stream, the Santa Cruz River, Tucson, AZ. This study will help to better understand the processes affecting bacterial concentration in effluent-dependent streams as well as address potential effects of incidental ground-water recharge in the Santa Cruz River on groundwater quality. Other field sites are currently being evaluated for further fieldwork in conjunction with the USGS.

PATHOGEN REGROWTH

Field sites are being evaluated to study a real-time distribution system where effluent is used for turf irrigation and also to compare the efficiency of different disinfection processes (UV and chlorine disinfection) on preventing regrowth. Results from this research project will greatly add to our understanding of the microbiological safety of water reuse practices as well as their potential environmental hazards and will ultimately help protect public health and our future groundwater resources.

Describe the major accomplishments over the life of the project, including their predicted or actual impact.

There is a need to understand the environmental fate of microorganisms and the potential for bacterial regrowth in reclaimed water used for crop irrigation so that future problems of food contamination via wastewater irrigation can be prevented. A laboratory study was conducted at the U.S. Water Conservation Laboratory to assess the survival and regrowth potential of bacteria present in tertiary-treated effluent used for crop irrigation and surface-water discharge as it passed through a model distribution system at bench scale (annular reactor). The results demonstrated that total coliforms and heterotrophic bacteria increased by three to four orders of magnitude, respectively, and that E. coli remained viable during the extent of the experiment (11 days). This research has established that although the reclaimed water met EPA standards for irrigation at the wastewater treatment plant, there is great potential for bacteria regrowth during transport that could place the water out of compliance at the point of intended use.

By FY04 we will have completed the column study looking at microbial resistance to antibiotics present as wastewater contaminants under groundwater recharge conditions.

By FY05 we will have completed fieldwork on fate and transport of wastewater contaminants.

with the USGS and the ARS Food and Feed Safety Research Unit. The information obtained from this study will help evaluate the degree by which water reuse practices will influence the transmission of antimicrobial resistance determinants to groundwater when wastewater is used for irrigation and/or groundwater recharge.

FIELD STUDIES

Field studies are in progress to study impacts of land application of wastewater on groundwater quality. A project was initiated in collaboration with the USGS to study the spatial and temporal distributions of wastewater contaminants in the surface water and in the underlying groundwater at an effluent-dependent stream, the Santa Cruz River, Tucson, AZ. This study will help to better understand the processes affecting bacterial concentration in effluent-dependent streams as well as address potential effects of incidental ground-water recharge in the Santa Cruz River on groundwater quality. Other field sites are currently being evaluated for further fieldwork in conjunction with the USGS.

PATHOGEN REGROWTH

Field sites are being evaluated to study a real-time distribution system where effluent is used for turf irrigation and also to compare the efficiency of different disinfection processes (UV and chlorine disinfection) on preventing regrowth. Results from this research project will greatly add to our understanding of the microbiological safety of water reuse practices as well as their potential environmental hazards and will ultimately help protect public health and our future groundwater resources.

Describe the major accomplishments over the life of the project, including their predicted or actual impact.

There is a need to understand the environmental fate of microorganisms and the potential for bacterial regrowth in reclaimed water used for crop irrigation so that future problems of food contamination via wastewater irrigation can be prevented. A laboratory study was conducted at the U.S. Water Conservation Laboratory to assess the survival and regrowth potential of bacteria present in tertiary-treated effluent used for crop irrigation and surface-water discharge as it passed through a model distribution system at bench scale (annular reactor). The results demonstrated that total coliforms and heterotrophic bacteria increased by three to four orders of magnitude, respectively, and that E. coli remained viable during the extent of the experiment (11 days). This research has established that although the reclaimed water met EPA standards for irrigation at the wastewater treatment plant, there is great potential for bacteria regrowth during transport that could place the water out of compliance at the point of intended use.

By FY04 we will have completed the column study looking at microbial resistance to antibiotics present as wastewater contaminants under groundwater recharge conditions.

By FY05 we will have completed fieldwork on fate and transport of wastewater contaminants.

By FY04 we will have finished evaluating field sites to examine microbial regrowth in real-time distribution systems and by FY05 we will have completed the sampling and assessment of the real-time distribution system.

By FY06, mitigation procedures for microbial regrowth in distributions systems will be developed and final reports and manuscripts will be prepared.

Publications:

Cordy, G., Duran, N.L., Bouwer, H., Rice, R., Kolpin, D., Furlong E., Zaugg, S., Meyer, M., Barber, L. Persistence of pharmaceuticals, pathogens, and other organic wastewater contaminants when wastewater is used for ground-water recharge. 2003. Proceedings of 3rd International Conference on Pharmaceuticals and Endocrine Disrupting Chemicals in Water. p. 195-196.

Jerman, J., N.L. Duran. Deterioration in Microbial Quality of Treated Effluent Used for Crop Irrigation During Distribution. ASM 103rd General Meeting, Washington, D.C. 2003. Abstract p. 582.

Spencer, K.L., N.L. Duran. Effects of Effluent-Dependent Stream on Microbial Loads and Groundwater Quality. ASM 103rd General Meeting, Washington, D.C. 2003. Abstract p. 609.

WASTEWATER IRRIGATION
AND
GROUNDWATER RECHARGE

Clinton F. Williams, Soil Scientist

PROJECT SUMMARY

Using wastewater for groundwater recharge is an attractive way for seasonal storage and additional water quality improvement through soil-aquifer treatment. The efficacy of soil-aquifer treatment for removal of organic carbon including pharmaceutically active compounds will be studied with soil columns in a greenhouse. Soil columns will also be used to study the fate of organic compounds in soil where crops are irrigated with sewage effluent. Additionally, samples of the upper groundwater below fields and urban areas (parks, golf courses, landscaping) with a long history of sewage irrigation will be taken and tested for organic agricultural compounds and pathogens.

Long-term storage of water via artificial recharge of groundwater (water banking) in times of water surplus provides a valuable source of water for use in times of water shortage. We plan to expand the potential of this technology, which is now pretty well restricted to permeable soils, to finer-textured "challenging" soils that need to be managed to minimize reductions in infiltration rates due to clogging.

OBJECTIVES

1. Determine the fate of organic compounds, such as pharmaceuticals and pharmaceutically active chemicals and disinfection byproducts, in vegetated soil columns (grass and alfalfa) in a greenhouse irrigated at various efficiencies with chlorinated secondary sewage effluent. The columns will also be used to determine fate of pathogens in sewage irrigated soil under a companion project under National Program 208, Food Safety (Protecting Groundwater Quality Below Waste-Water Irrigated Fields).

2. Analyze samples of the upper groundwater below agricultural fields and urban irrigated areas (golf courses, parks, landscaping) with a long history of sewage irrigation for pharmaceuticals, disinfection byproducts and other chemicals to evaluate effects of sewage irrigation on groundwater quality. The samples will also be analyzed for pathogens under a companion project.

3. Carry out field and laboratory research to develop optimum management procedures for basins that infiltrate secondary or tertiary sewage effluent for recharge of groundwater and water quality improvement through soil-aquifer treatment. Focus will be on relatively fine-textured soils where clogging, crusting, and fine-particle movement can seriously reduce infiltration rates, and hence, recharge capacities.

NEED FOR RESEARCH

Description of the Problem to be Solved

Increasing populations and finite water resources necessitate more water reuse (Asano, 1998; Bouwer, 1993 and 1999). Also, increasingly stringent treatment requirements for discharge of sewage effluent into surface water make water reuse more attractive. The present focus in the U.S. is on sustainability of irrigation with sewage effluent and of soil-aquifer treatment, particularly the long-term fate of synthetic organic compounds (including pharmaceutically active chemicals and disinfection byproducts) in the underground environment (Lim et al., 2000; Bouwer, 2000; Drewes and Shore, 2001). The fate of pathogens and nitrogen also needs to be better understood. In Third World countries, simple, low-tech methods must be used to treat sewage for reuse. These methods include lagooning, groundwater recharge, and intermittent sand filtration (Bouwer, 1993). While most standards or guidelines for irrigation with sewage effluent focus on indicator organisms and pathogens, other water quality aspects must also be considered (Bouwer and Idelovitch, 1987).

Long-term effects of irrigation with sewage effluent on soil and underlying groundwater must be better understood so that future problems of soil and groundwater contamination can be avoided. Potential problems include accumulation of phosphate, metals, and strongly adsorbed organic compounds to the soil matrix, and of salts, nitrate, toxic refractory organic compounds, and pathogenic microorganisms in groundwater. Water reuse for irrigation is a good practice, however, care should be taken to prevent deterioration of groundwater quality (Bouwer et al., 1999; Bouwer, 2000). Typical concentrations of some potentially endocrine disrupting chemicals in sewage effluent are shown in Table 1, taken from Lim et al., (2000). Other pharmaceuticals such as lipid regulators, antiepileptics, analgesic/anti-inflammatory drugs, and antibiotics can also be present. The microbiological safety of water reuse is also an important issue, particularly when wastewater is used for the irrigation of fruits and vegetables that are eaten raw or brought raw into the kitchen, as discussed in a companion project under National Program 108. It is of utmost importance to understand the risks associated with wastewater used for irrigation and the factors affecting the deterioration of wastewater effluent after it leaves the treatment plant. There is growing concern about the potential for microbial regrowth in the conveyance /distribution systems where the effluent is transported over long distances to the irrigated areas (mostly with pipelines). The aim of this research is to develop technology for optimum water reuse, to evaluate the role that groundwater recharge and soil-aquifer treatment can play in the potable and nonpotable use of sewage effluent (Bouwer, 1985) and to determine the safety of tertiary effluent used for irrigation of foods, particularly where effluent is transported for relatively long distances in pipes or open channels where regrowth of pathogens and other processes can occur.

Relevance to ARS National Program Action Plan

This research directly addresses national and global problems dealing with safety of food produced in fields that have been irrigated with sewage effluent or with effluent contaminated water. It also addresses water conservation and integrated water management through water reuse. These issues occur or emerge in many parts of the U.S. and the rest of the world wherever there is not enough water to meet all demands for municipal, industrial, and agricultural (irrigation) purposes. All objectives fall under National Program 201, Water Quality and

Management. Objectives 1 and 2 fall under Problem Area 2.5 (Waste Water Reuse), Goal 2.5.3 (Waste Water Standards). They address water conservation and integrated water management through water reuse. Objective 3 addresses Problem Area 2.3 (Water Conservation Management), Goal 2.3.1 (Water Conservation Technologies).

Table 1. Typical concentrations of some EDCs in treated sewage effluent (Lim et al., 2000).

Compound	Secondary Treatment	Tertiary treatment
Estrogen (ng/L)	38	3
Testosterone (ng/L)	50	2
Estrone (ng/L)	1.4 - 76	1.8 - 3.6
17β-estradiol (ng/L)	<5 - 10	2.7 - 6.3
Estriol (ng/L)	<10 - 37	
Ethyinylestradiol (ng/L)	<0.2	<0.2
Nonyl-phenol (μg/L)	<0.02 - 330	
2,4-dichlorophenol (μg/L)	0.061 - 0.16	
Alkylphenols (total)(μg/L)	27 - 98	
Bisphenol A (μg/L)	0.02 - 0.05	
Arsenic (μg/L)	1.3 - 23	
Cadmium (μg/L)	<0.02 - 150	
Lead (μg/L)	0.1 - 44	

Sources: Shore et al. 1993a, Desbrow et al. 1998, Lee & Peart 1998, Blackburn & Waldock 1995, Rudel et al. 1998, Johns & McConchie 1995, Feigin et al. 1991, Bahri 1998.

Potential Benefits

Benefits from attaining the objectives include safe reuse of sewage effluents for irrigation from the standpoint of food safety and groundwater quality protection. Control measures and actions or activities that can be used to prevent, reduce, or eliminate the microbial and chemical food safety hazard will be developed. Water reuse will be more common and the practices will be safer for public health. Such reuse will help in production of adequate food and fiber for growing populations.

Anticipated Products

1. Improved techniques of sewage treatment and system management for safe and sustainable water reuse with minimum adverse effects and in environmentally acceptable ways.
2. New guidelines for irrigation with wastewater to protect groundwater and surface water quality.
3. New procedures for managing groundwater recharge basins to improve their effectiveness, especially where soils are relatively fine-textured.

Customers

Customers of the research include the public, farmers and farm workers, water planners and managers, government regulators, consulting engineers, water districts and municipalities, wastewater treatment plant operators and managers, and the turf, landscape, and golf-course industries.

SCIENTIFIC BACKGROUND: Refer to 2002 Annual Report

APPROACH AND RESEARCH PROCEDURES: Refer to 2002 Annual Reportg

PHYSICAL AND HUMAN RESOURCES: Refer to 2002 Annual Report

MILESTONES AND EXPECTED OUTCOMES

Milestone Time Line: Publication and presentation of results as significant outcomes arise. Demonstration and training programs will be held with potential users as required (Table follows).

Information should be available on the underground fate of sewage chemicals like synthetic and natural organic compounds below sewage irrigated fields and their potential effect on groundwater below sewage irrigated fields or infiltration basins used for artificial recharge of groundwater with sewage effluent. Depending on the results, these outcomes should have a significant effect on water reuse practices around the world, either giving them the green light or a warning about potential adverse effects on human health and underlying groundwater. If the latter is true, best management practices will be developed and tested. The pathogen aspects will be the responsibility of the microbiologist on a related project. The organic chemical aspects of recharge and soil-aquifer treatment systems, as well as principles and practices of water reuse and groundwater recharge in general will be the responsibility of the engineer and chemist.

Since the research addresses practical and real-world problems, it should not be difficult to translate the results into useful concepts. Additional investigations are needed and will be added to the project as funds become available.

Milestone timeline:

Research Study Components	**end of year 1**	**end of year 2**	**end of year 3**	**end of year 4**	
Greenhouse soil columns	operation, management and sampling for irrigation and groundwater recharge procedures, chemical analyses, program completed	operation, continued results of chemical analysis interpreted changes in column management as indicated, consider applying animal manure and analyze inflow and outflow for pharmaceuticals	operation continued, manuscripts prepared, spiking infiltration water with tracers and specific chemicals	final reports and manuscript prepared, plan and perform future studies	fin ma pl fu
Field reconnaissance	select sites of wastewater irrigated fields and urban areas and sample water and groundwater for wastewater chemicals	include more sites in other parts of the U.S.	expand sampling program to other countries	prepare final reports for presentation and publication of papers, plan and perform future studies	pr pr pu pl stu
Clogging research	set up laboratory and field studies for soil clogging and mitigation in recharge basins, study crusting and fine particle movement	continue laboratory and field studies for maximizing infiltration rates in fine-textured soils	continue laboratory and field studies for maximizing infiltration rates in fine-textured soils	write papers on best management practices, plan and perform future studies	wr ma pl stu

PROGRESS:

A new scientist was hired on this project during FY03. Field lysimeters were installed in six locations where sewage effluent is used for irrigation. Drainage collected from the lysimeters will be analyzed for various organic and inorganic contaminants to determine the environmental impacts and sustainability of using reclaimed sewage effluent for irrigation. Data collection continued for the column studies where sewage effluent is used for irrigation at various efficiencies.

Subordinate Projects

Constructed wetlands are potentially an important means of treating sewage effluent before release to surface water bodies. The Trés Rios constructed wetland at the Phoenix Arizona 91st Avenue Sewage treatment plant experienced a failure of the bulrush population in the wetland. The Bureau of Reclamation has funded a study to evaluate chemical and biological conditions that may have lead to the decline of the plant population of the wetland. This project was initiated in July of 2003.

A set of preliminary values of oxidation-reduction potentials of areas in which bulrush survived and where it died out was collected. The wetland was then drained and the pond bottom reshaped in portions of the pond. Samples were taken from the experimental areas and are currently being analyzed. The wetland was refilled and then replanted. The site will be released by the contractor to the City of Phoenix in August of 2003. At that time the monitoring of redox will be resumed.

A Ph.D level graduate student in the Ag. and Bio Engineering department has been recruited to conduct chemical, biological, and operational evaluations of the wetland to isolate the cause of the decline of the bulrush population.

FY04 - Field lysimeters will be characterized for flow dynamics and sportive properties. Leachate will also be collected for water quality analysis, including organic and inorganic contaminants. Studies will also be initiated in cooperation with the Weber Basin Water Conservancy District and the South Davis Sewer District to determine suitability and best management practices in reusing reclaimed sewage effluent in municipal secondary irrigation systems.

FY05 - Continue data collection from the field lysimeters. Collect data from secondary irrigation system and investigate various management practices that will provide for the safe use of reclaimed sewage effluent in a municipal setting.

FY06 - Continue data collection from the field lysimeters and secondary irrigation system. Investigate the fate and transport of organic contaminants found in sewage effluent and publish results.

SURFACE IRRIGATION WATER QUALITY AND MANAGEMENT

Theodor S. Strelkoff, Research Hydraulic Engineer
Floyd J. Adamsen, Soil Scientist
Eduardo Bautista, Research Hydraulic Engineer
Douglas J. Hunsaker, Agricultural Engineer
Albert J. Clemmens, Research Hydraulic Engineer
Robert J. Strand, Electrical Engineer

PROJECT SUMMARY

Surface irrigation is the most widely used irrigation method in the world. In the US, over 50% of irrigated land is watered by surface means. It is the most inexpensive method, in terms of capital outlay, power requirements, and maintenance costs. Traditional surface methods are labor intensive. Poor uniformity of application, and excessive runoff and deep percolation, often carrying agricultural chemicals into the environment, are common. The complexity of the hydraulics of surface systems has, until recently, made rational design very difficult. Accordingly, many surface systems are built and operated without the benefit of any technical design. The proliferation of computers has now made numerical solutions of the hydraulic equations easily attainable, and is putting design of surface irrigation systems and their operation on a par with other engineering disciplines -- with reliance on multiple analyses (simulations) with trial values of the design variables in the search for an optimum.

The proposed research is intended ultimately to provide guidance in the design and operation of surface systems, both traditional and innovative. The investigators will collaborate with several ARS sites addressing all four of the NP201 research initiatives. Intermediate goals are (1) simulation of the transport and fate of water, sediments, and nutrients such as phosphorus and nitrogen by irrigation in furrows, border strips, and basins of various types, along with attendant field studies, (2) software for presenting overviews of simulations to aid in the search for an optimum, (3) software to assist in evaluating extant field conditions on which irrigation performance depends.

OBJECTIVES

1. Develop validated software (a) for simulating surface-irrigation hydraulics, (b) for assisting in design and management of such systems, and (c) for estimating the field parameters that bear upon system behavior.
2. Develop guidelines for design and operation of drain-back and other surface-drained level basins to improve water use in surface irrigation, while maintaining farm profitability and sustainability.
3. Develop validated surface-irrigation models incorporating the fate and transport of sediments, phosphorus, and nitrogen, including their ultimate off-site discharge.
4. Develop guidelines for water and nutrient management under surface irrigation for minimizing introduction of nitrogen into surface and ground waters while maintaining soil fertility, crop yields, and farm profitability and sustainability.

NEED FOR RESEARCH

Description of the Problem to be Solved

Surface irrigation accounts for half of the irrigated land area in the U.S. and over 90% worldwide. Many systems are built and operated without adequate technical input, with consequent low uniformity and efficiency of water application. Yet, water supplies for irrigation are limited and likely to decline due to competition from environmental and urban water demands. Improved management and conservation will be required to maintain current levels of crop production; at the same time, demand for food is expected to grow. Science-based criteria for design and management of surface systems can often improve surface irrigation performance to levels commensurate with pressurized systems at substantial savings in capital costs and energy. Irrigated agriculture also contributes to non-point source pollution of groundwater and surface waters with nitrogen and phosphorus. Application of nitrogen fertilizer in the irrigation water is widely practiced but often leads to nonuniform, excessive application and contributes to nitrogen contamination of the groundwater. Tailwater runoff can carry sediments, nitrogen, and phosphorus to surface streams. Improved design and operation of surface irrigation systems and improved nitrogen application practices should improve agriculture's utilization of water and reduce its adverse effects on the environment.

Relevance to ARS National Program Action Plan

The research is part of NP201, Water Quality and Management. The project falls under Component 2, Irrigation and Drainage Management. Objectives 1 and 2 deal with agricultural water conservation, while 3 and 4 deal with the effects of irrigated agricultural on the environment. All fit under Problem Area 2.3 (Water Conservation Management), Goal 2.3.3 (Agricultural Water Conservation and Environmental Quality). Objective 3 concerns also Problem Area 2.6 (Erosion on Irrigated Land), Goal 2.6.2 (Irrigation/Erosion Model).

Potential Benefits

Process-based predictive tools can be effectively used to examine the consequences of various system designs and management practices on the utilization of water and nutrients by the crop and on the contamination of surface water and groundwater by irrigated agriculture. These tools can become the basis for improving practices that conserve water, minimize fertilizer costs, and protect the environment, while maintaining yields of crops under irrigation, particularly with surface methods.

Anticipated Products

1. A process-based model of surface irrigation, including water flow, sediment movement, and the movement over the field surface of chemicals, both dissolved in the water and attached to sediment particles. For studies on fate and transport of nitrogen, the model is to be linked with other models, developed at collaborating laboratories, simulating soil physical and chemical processes.

2. Design and management-aid software, integrated with the simulation model.

3. Guidelines and recommendations, grounded in contemporary scientific and engineering principles, for improving surface irrigation performance and for reducing the impact of irrigation on the environment, while maintaining or improving crop production and quality.

Customers

The NRCS (Natural Resources Conservation Service, particularly through the National Water and Climate Center and Thomas L. Spofford, Irrigation Engineer) has supported our development of surface-irrigation design and management tools and has promoted these for use at its field offices. We thus expect our main customers to be the NRCS, as well as agricultural consultants, mobile field labs, and extension agents, with farmers as the ultimate beneficiaries (particularly in the case of software). We plan to have these groups review the software and predictive tools throughout the development process, as well as the ultimate recommended practices.

SCIENTIFIC BACKGROUND: Refer to 200 Annual Report

APPROACH AND RESEARCH PROCEDURES: Refer to 2002 Annual Report

PHYSICAL AND HUMAN RESOURCES: Refer to 2002 Annual Report

MILESTONES AND EXPECTED OUTCOMES

Expected outcomes include an extended surface-irrigation-simulation model (SRFR) with fate and transport of water, sediment, phosphorus, and nitrogen in the irrigation stream. The simulation model is to be part of an integrated user-friendly suite, SRFRSuite, including design/management aids and field-evaluation components. We expect to publish guidelines for the design and management of surface-drained level basins and for fertigation management in surface irrigation.

Milestone Timeline

Research Component	End of year 1	End of year 2	End of year 3	End of year 4	End of year 5
SRFR Suite: hydraulics	Select platform languages	Complete field-evaluation component	Complete furrow-design component		Complete SRFR Suite
Surface-drained level basins		Complete field studies of GSDLB (grid-supplied & drained level basins)	Guidelines for DBLB (drainback level basins)	Complete modeling of GSDLB	Guidelines for design and management of GSDLB
SRFR constituent simulation	Complete sediment transport component	Complete phosphorus fate and transport	Validate and calibrate sediment and phosphorus models	Complete N transport in the irrigation stream Couple to soil-water/ chemistry model	Validate and calibrate nitrogen model
Nitrogen fertigation management		Field studies of nitrogen uniformity and efficiency completed	Preliminary guidelines on fertigation with surface irrigation issued		Final guidelines on N fertigation with surface irrigation

PROGRESS:

IRRIGATION SYSTEM EVALUATION

The fiber-optic advance and opportunity time sensor, developed in prior years has been upgraded with a sensor to turn off the display to save battery life. We have also discussed commercialization of this device with a CRADA partner. In addition, we have extended this concept of detecting the presence of water to produce a digital depth sensor. A prototype has been constructed for testing in the lab. We are in the process of producing a field prototype version that we can test in the field. The CRADA partner has expressed more interest in this device and may cooperate with us on setting this device up for field testing. Durability and ease of construction are the factors that might limit commercialization and thus will be the focus of the field tests.

FERTIGATION

Efficient injection of fertilizer into irrigation water in surface systems depends on predicting post-irrigation chemical distribution. Fertigation experiments were conducted in the Coachella Valley Irrigation District in California. Testing of samples from FY02 are complete and data analysis begun. Analyses of water and soil samples from FY03 are under way. Data from FY02 show that application uniformity of the water was 0.7 to 0.8. Application uniformity of bromide tracer ranged from 0.15 to 0.6. Injection over the entire irrigation gave the best application uniformity. Timing refinements are needed to improve performance.

MODELING SOIL MOISTURE AND CHEMICAL TRANSPORT WITH SURFACE IRRIGATION

Predicting chemical transport under surface irrigation requires linking soil-water flow, chemistry, and surface-flow models. A first step in linking the soil moisture and chemistry model, HYDRUS (ARS, Riverside, CA), to SRFR (ARS, Phoenix, AZ) was made by using a time dependent hydraulic head from a border strip water-depth hydrograph calculated by SRFR for input to HYDRUS. It proved necessary to modify HYDRUS to account for the cutoff of water supply to the soil as the surface water recedes, while allowing access of soil pores to the atmosphere as moisture is redistributed in the soil following recession.

MODELING UNSTEADY INFILTRATION FROM FURROWS

A simple and fast alternative to formally linking soil-moisture models (HYDRUS) with furrow-hydraulics models (SRFR) is an algorithm in SRFR designed to approximate infiltration with a variable wetted perimeter. HYDRUS-2D was used to simulate furrow infiltration at various wetted perimeters and furrow spacings through accurate solution of the Richards equation for unsaturated flow in a homogeneous, isotropic soil medium. The results were compared with the SRFR algorithm and also a well known NRCS approximation. In the limited range of cases tested, the SRFR algorithm was found to consistently underpredict infiltration, while the NRCS formula consistently overpredicted it.

MODELING SOIL EROSION AND PHOSPHORUS TRANSPORT

Coding the sediment transport module in SRFR continues. The anomalous negative transport capacities calculated for very small particles by the Laursen formula have been eliminated by the correction of an inconsistency in its derivation, but, still, the calculated transport capacities are suspiciously low. The problem of extrapolation beyond the range of empirical data remains. The hope is that there is sufficient physical basis for the formula to allow limited extrapolation. Experimental corroboration with the field studies at ARS, Kimberly, ID, will either confirm or condemn this approach.

MEASURING SOIL EROSION AND PHOSPHORUS TRANSPORT

Laboratory tests at ARS, Kimberly, ID, cooperating with USWCL, showed phosphorus (P) quickly released from suspended sediment to the water. Field tests showed most sediment was transported as small aggregates (<0.05 mm for a silt loam soil); the P concentrations associated with each sediment size were similar. Diffusion of phosphorus, P, from furrow soil did not appear to be the main mechanism adding dissolved P to furrow flow. Desorption of P from transported sediment seems to contribute the largest portion of dissolved P to furrow water. Most of the P in the tailwater is associated with sediment which may or may not settle out, but any P dissolved in the water typically remains with the tailwater, to flow to the receiving river.

PHOSPHORUS DESORPTION IN SURFACE IRRIGATION

Two sets of experiments have been performed in a flume with various water depths and velocities over a phosphorus-enriched soil surface and with neither infiltration nor erosion. Analysis of the differing entrainment results in the two sets is under way, with the difference in ambient temperatures (summer and late fall) as a likely cause. Infiltration, controlled by a porous drain at constant negative pressure, will be studied next. Partially complete design for the drain is based on simulations of soil moisture flow from the bulk water on the soil surface to the bulk water in the porous pipe, via solution of the Richards equation (HYDRUS-2D, ARS, Riverside, CA).

GRID-SUPPLIED AND DRAINED LEVEL BASINS

A study was initiated in collaboration with Louisiana State University to develop design and management recommendations for grid supplied and drained level basin systems. Such systems are being adopted in Louisiana and Arkansas, even though they are not sanctioned in state NRCS guidelines, due to concern over drainage of excess rainfall. Data is being collected on a farm on which many traditional graded furrow systems have been converted to level basins. Such data will help document claims made by the farmers about the production and cost advantages of level basins as compared to graded furrows.

SURFACE IRRIGATION PARAMETER ESTIMATION SOFTWARE (SIPES)

We have continued the development of software for estimation of surface irrigation field parameters. The software will assist action agencies, such as NRCS, with their parameter-estimation needs and will provide a vehicle for comparing alternative methods. Progress has been made in the development of screens and data-file structures needed to capture the inputs required by the various methods. Only simple volume-balance methods have been programmed so far, and initial studies have been conducted to contrast the effectiveness of those methods and to assess their limitations.

ERRORS INHERENT IN SIMPLIFIED INFILTRATION-PARAMETER ESTIMATION METHODS

Simple methods for estimating infiltration in surface irrigation from measured stream parameters require estimates of average cross-sectional area of the surface water flows. A simulation study was conducted to determine the degree of error in estimated time to infiltrate a target depth as a consequence of errors in assumed average cross section or measured advance times. For soils well characterized by the Merriam and Clemmens Time Rated Infiltration Families, the errors generated in the corresponding One-Point method proved moderate and well behaved even for infiltration times well in excess of the advance time. And as expected, the larger the field slope, the smaller the error.

IMPLICATIONS OF UNCERTAIN FIELD PARAMETERS FOR BORDER IRRIGATION MANAGEMENT

A study was performed on the effect of variations in infiltration characteristics (relative to the values assumed in design) on border irrigation performance. The study is part of a broader effort aimed at developing design and management recommendations given uncertain design information. Current results suggest that border systems, if properly designed, have some tolerance for erroneous design information. However, compensating for the effect of such uncertainties requires an in-depth understanding of the hydraulic characteristics of the particular system.

MEASURING FURROW FLOW AND EROSION

In prior studies of furrow erosion, the flumes used to measure water flow in the furrow restricted flow, so that sediment deposited upstream from the flume. Placing the flume lower caused difficulties in getting downstream water and sediment samples, in addition to causing flume submergence: placing them higher resulted in deposition of sediment upstream. A new flume was designed for furrow erosion studies by engineers at the U.S. Water Conservation Lab, Phoenix, AZ and the Northwest Irrigation and Soils Research Lab, Kimberly, ID, such that changes in upstream depth and velocity are minimized throughout the range of flows. Prototypes were constructed with sheet steel and a commercial version was manufactured in fiberglass by a local manufacturer of flumes. Studies on the performance of these flumes is ongoing.

Alfalfa is a profitable crop for farmers throughout the U.S., widely used in dairy production and as feed for horses, but in arid and semiarid areas the water use by alfalfa is high. A study, aimed at improved water management was conducted in Arizona by the U.S. Water Conservation Laboratory (USWCL). Results show that irrigation water applications to alfalfa can be reduced by as much as 10% from the current irrigation scheduling-software-generated recommendations without significant loss of yield and resulting, also, in less contamination and irrigation water leached below the root zone. These results will be useful to producers, consultants, other researchers, and policy makers.

Natural Resources Conservation Service (NRCS) engineers applying USWCL border-irrigation design-aid software have occasionally been frustrated by hardwired limits on trial values of design variables, intended to steer inexperienced users away from potentially troublesome combinations of values. USWCL engineers have re-examined these limits and the penalties for selecting inappropriate values. A two-tiered system was introduced into the software allowing experienced designers to select their own limits on input variables, while guiding the less experienced toward Asafer@ values. The adjustments make application of the design aid software more attractive to action agencies and thus help to put more science into the design and management of surface irrigation systems aimed at increasing uniformity and efficiency.

Field evaluations of surface-irrigation performance depend upon measurements of advance and recession, which are often difficult to obtain under field conditions. USWCL engineers designed a remotely operated device for measuring when the water arrived (advance) and when it disappeared from the surface (recession), which would make it unnecessary to enter the wet field. Development has been completed on a new fiber-optic advance and opportunity time sensor with no moving parts. The device can be used by action agencies and state-funded mobile irrigation laboratories for irrigation evaluations and infiltration parameter estimates, with the ultimate goal of improving irrigation management in surface systems.

In general, in future years, increased coordination between the modeling and field studies is planned.

In FY2004 simulations of post-irrigation fertigation-chemical distributions will be extended to basins with no runoff, and compared with field results to discern the role of mixing or diffusion of the fractions, ignored in the present model. A new grower cooperator has allowed progress to accelerate. Analysis of samples from the field studies should be completed by the middle of FY04 and the data used to develop guidelines for producers to use when applying fertilizer in the irrigation water. The development of complete fertigation guidelines will require the addition of a dispersion term to the existing chemical transport model and completion of linkage to a subsurface flow model such as HYDRUS. These tasks will be the focus of the fertigation work in FY04 and FY05.

During FY2004, we plan to continue development of an inexpensive sensor for shallow water depths to provide additional data for estimating field values of infiltration and roughness. We plan to seek assistance from a CRADA partner to commercialize the product.

Calibration models, which account for the effects of soil salinity on the output of an inexpensive, time domain reflectometer (TDR) soil moisture sensor, will be developed by the end of FY2004, subject to time constraints. This will provide the capability of the sensor to measure more accurately soil water content in fields where high soil salinity decreases the reliability of TDR measurements.

During FY2004, programming for an integrated, true Windows version of the surface-irrigation software should be under way, with a conclusion in FY2006. Acquisition of additional IT staff, expected early FY2004, should keep this project on track in accord with the Project Plan.

The major part of the programming for the sediment fate and transport component of SRFR should be completed by the end of calendar 2003, with the phosphorus component following in FY2004; calibration and validation should be completed in FY2004-FY2005.

In FY2004, our cooperators at ARS, Kimberly will continue to analyze field and laboratory data to develop relationships for modeling transfer of phosphorus from sediment to flowing water.

Efforts will be continued during FY 2004 to equip the SRFR program with infiltration models more physically based than the purely empirical formulas now in use. Formal linkage with existing stand-alone software based on solutions of the Richards equations for soil moisture flow is expected in FY2005.

Development of SIPES is planned to occur in phases reflecting the different parameter-estimation methods, with periodic releases to cooperators during FY2004 and beyond. A newly developing cooperative agreement with Oregon State University may provide graduate-student help with programming the different phases. The approaches will be assessed and recommendations made also via informal collaborative agreements stemming from scientists' participation in the ASCE Task Committee on surface-irrigation parameter estimation, to which USWCL scientists contribute substantially. We expect to complete a comprehensive report on this work in 2005.

We will continue the theoretical studies on field-parameter uncertainty in design and management of level basins and borders through FY2004, with the objective of developing graphical tools that can be used for assessing the effect of uncertain infiltration inputs on irrigation performance. In FY2004 we will also expand the work to include furrow irrigation systems. Beginning in FY2004, we will pursue field studies in collaboration with NRCS to assess performance of actual NRCS surface irrigation designs and the contribution of field-wide and seasonal variation.

By the end of FY05, we expect to have sufficient field data on the performance of level basins in Louisiana and Arkansas to provide guidelines for grid-supplied and drained level basins. Field data collection efforts have been hampered by the distance to field sites (>1000 miles). We expect additional data to be collected during FY04 and FY05, with assistance from Louisiana State University, ARS Baton Rouge, and NRCS, Little Rock, AR. These data collections will provide support to efforts to document the performance of these irrigation/drainage systems and help to validate the mathematical models developed.

We expect to produce a mathematical model to describe irrigation and drainage from grid-supplied level basins by the end of FY06, in cooperation with Louisiana State University. We are currently investigating alternative formulations of the governing equations to deal with the complexity of the grid-supplied systems, which our current 1-dimensional models cannot describe and which cannot be adequately handled by our existing 2-dimensional formulations either.

By the end of FY04, we expect to complete the numerical analyses to provide some preliminary guidelines for drain-back level basins. These will be augmented with further analysis through use of the mathematical models under development by the end of FY06.

Conversations with cooperators suggest that farmers continue to convert from traditional graded (furrow and border) to level-basins (including drainback and grid-supplied-and-drained variations) in various parts of the country. Reasons expressed for this conversion include improved water management and reduced irrigation labor costs. Expansion of this technology in humid areas is hampered by local NRCS rules which do not support surface irrigation systems with zero-grade. Hence, farmers are converting their systems in the humid areas exclusively with their own financial resources.

Surface irrigation design and operating guidelines and tools have been transferred to a variety of clients through personal visits (e.g., NRCS, cooperative extension, experiment stations, state mobile irrigation labs), software used world wide (available on USWCL web pages -- with a link from the NRCS Water and Climate Center web page), and through technical presentations at irrigation meetings and conferences.

Publications:

Strelkoff, T.S., Bautista, E., Clemmens, A.J. Errors inherent in the simplified infiltration parameter estimation. Proceedings of 2nd Int. Conference on Irrig. & Drain. 2003. p. 735-745.

Tamimi, A.H., Clemmens, A.J., Bautista, E., Strelkoff, T.S. SIPES - Surface Irrigation Parameter Estimation Software. Proceedings of 2nd Int. Conference on Irrig. & Drain. 2003. p. 615-624.

Abbasi F., Adamsen, F.J., Hunsaker, D.J., Feyen, J., Shouse, P., van Genuchten, M.Th. Effects of flow depth on water flow and solute transport in furrow irrigation: Field data analysis. J. Irrig. and Drain. Engineerimg. 2003. v. 129. p. 237-246.2.

Zerihun, D., Sanchez, C.A., Farrell-Poe, K.L., Adamsen, F.J., Hunsaker, D.J. Performance indices for surface N fertigation. J. Irrig. and Drain. Engineering. 2003. v. 129. p. 173-183.

Bautista, E., Strelkoff, T.S., Clemmens, A.J. Border irrigation management implications of imprecise infiltration parameter estimates. Proceedings of 2nd Int. Conference on Irrig. and Drain. 2003. p. 603-614.

Perea, H., Strelkoff, T.S., Simunek, J., Bautista, E., Clemmens, A.J. Unsteady furrow infiltration in the light of the Richards equation. Proceedings of 2nd Int. Conference on Irrig. and Drain. 2003. p. 625-636.

THE WESTERN RIVERS INITIATIVE FOR SUSTAINABLE AGRICULTURE

Albert J. Clemmens, U. S. Water Conservation Lab, Phoenix AZ
Tom Trout, San Joaquin Valley Agricultural Sciences Center, Parlier CA
Don Suarez, George E. Brown Salinity Lab, Riverside CA
Dale Westermann, Northwest Irrigation & Soils Research Lab, Kimberly ID

The Western Rivers Initiative for Sustainable Agriculture

2/14/03 Draft

Background: Increasing demands for limited water supplies have reduced the physical, chemical, and biological quality of most rivers in the western United States. Growing environmental water needs for these rivers and increasing urban demand have put pressure on agriculture to use water more wisely while continuing to provide food and fiber for the nation. A holistic view is needed to evaluate the role of agriculture within western river basins in order to provide effective field, farm, and watershed management practices that protect the water resources and ecosystems within these river basins. This initiative focuses on the three major river basins within the Western United States: the Columbia-Snake Rivers, the Sacramento-San Joaquin Rivers, and the Lower Colorado River, including Central Arizona.

The Lower Colorado River is currently over-allocated. California is being forced to reduce its annual use from roughly 5.3 to 4.4 million acre feet. At the same time, water demands are increasing from urban expansion in Southern California, Southern Nevada, and Central Arizona; Native American Entitlements; Mexican urban and agricultural sectors; and environmental needs, including restoring fresh water flow to the Sea of Cortez. With less water available for agriculture, irrigation systems will need to be more efficient and management of soil salinity will become more difficult. Artificial groundwater recharge is expanding , but with little knowledge of the effects on water availability and groundwater quality.

Management of the Sacramento-San Joaquin Rivers is a critical issue in the central valley of California. Water supplies available for agriculture are declining. Drainage restrictions on the west side of the San Joaquin Valley threaten sustainability of agriculture there. These cutbacks and restrictions result from the need to improve the ecosystem in these rivers and in the Delta. To date, groundwater issues have been largely ignored, but they will play an increasing role in future water management.

Management of the Columbia and Snake Rivers has been a balancing act among in-stream flows for salmon and other fish, diversions for irrigation and urban use, and hydroelectric power generation. The aquatic conditions of the Snake and Columbia are degraded in terms of elevated water temperature, excess nutrients, and altered stream flow and timing. Groundwater withdrawals and declining watertables are also reducing stream flows. In some areas, groundwater quality is also degraded.

Justification: Scientific information is lacking on the impact of various agricultural management practices on surface water quality, groundwater quality, air quality, soil quality, and available water supplies. Obtaining reliable scientific information is essential for making choices in managing western rivers considering the wide array of issues involved. These issues are often site-specific, and their impact varies widely even within the same river basin. We propose to study these issues within the three major river basins in a more holistic way. By taking this broad perspective, basic relationships identified across the wide variety of situations can be organized and applied beyond the study area. The problems have been broken down into a number of technical issues that can be addressed across these three river basins, listed below.

Decreasing water supplies and water transfers: Erratic natural precipitation and unresolved Native American and environmental water demands have made water supplies less reliable, which is likely to place more emphasis on agricultural water conservation and water transfers. We currently do not have sufficiently accurate data on water consumption and knowledge of the net impact of various proposed practices that could potentially reduce agricultural water diversions and free up water for transfers and environmental uses. Land retirement, both temporary and permanent, has been proposed to provide water for transfer. However, such retirement must be carefully managed to avoid wind blown dust and/or soil salinization. PM-10 emissions are a considerable problem in the central valleys of California and Arizona and are likely to be an issue with any practices that reduce flow to the Salton Sea. Other methods for reducing agricultural water consumption may or may not be feasible. These all point to the need for better water budgets to document potential water available for transfer. Irrigation performance improvement, in many cases, would provide opportunities for real water savings.

Conjunctive use of surface and groundwater/groundwater recharge: In most states, laws governing groundwater differ from laws governing surface water. However, management of groundwater supplies has become a major issue in most western states. Conjunctive management of both surface and groundwater supplies is essential for long-term sustainability of water supplies. This will require a better understanding of the links between surface and groundwater. Also, groundwater recharge is being promoted to store surplus surface water for later reuse. The effectiveness of getting water into the ground and recovered needs further study.

Water reuse: Water not consumed by agricultural and urban activities is potentially available for reuse. However, this water is typically degraded in quality such that reuse may not be straightforward. Reuse of saline drainage water poses many challenges. The complication in sequential use of increasingly saline waters can be daunting. Volumes of municipal and agricultural processing wastewaters are increasing and their reuse is an important source of water. However, methods for effectively dealing with inorganic ions, chemical compounds, and pathogens are needed to protect public health and avoid contamination of groundwater supplies.

Salinity management: Saline soils and agricultural areas with saline groundwater and high watertables are a significant challenge for irrigated agriculture. Even urban areas are experiencing increases in surface and groundwater salinity. The regions affected by salinity issues are expected to expand over the next decades. Better local and regional management strategies are needed to avert salinization of susceptible regions. Regional assessment of salinity impacts are needed as well as quantification of off-site impacts.

On-field practices to protect and improve river quality (TMDLs): Runoff and deep percolation from agricultural fields often contain sediments, nitrogen, phosphorus, salts, pesticides and trace elements, and may be at a higher temperature. When return flows enter streams and rivers, they usually adversely impact their quality and biological functioning. Considerable effort has gone into developing on-farm management practices for reducing this impact under rainfed agriculture in the Midwest. A similar effort is needed for arid irrigated agriculture in the west – development of on-farm management practices for improving irrigation return flow water quality.

Protecting water resources within the context of a viable agricultural and rural community: Agricultural and rural communities are an important part of the arid west and supply a critical component of our nation's food supply. However, they are more vulnerable to water resources limitations than other regions, both in terms of quantity and quality. Any solutions must consider the impact on these communities and our food supply.

Proposed Research Activities:

ARS is uniquely poised to provide answers to important issues that currently limit the effective management of agricultural water use within these river basins. The proposed research augments ongoing research at the U.S. Water Conservation Lab., Phoenix, AZ; the San Joaquin Valley Agricultural Sciences Center, Parlier, CA; the George E. Brown Salinity Lab., Riverside, CA; and the Northwest Irrigation & Soils Research Lab., Kimberly, ID. Application of these results will help to mitigate the effect of agriculture on the water quantity and quality of these rivers. The suggested new/expanded research areas are:

- Assessing and Managing Water Supplies: Research is needed to improve our understanding of the overall hydrology and water balance within the basins. This present lack of understanding limits our ability to rationally manage and allocate water supplies. Critical information includes basin-wide estimates of water use by both agricultural and native plants, and understanding the interactions between groundwater and surface waters and their sustainable conjunctive use. Remote sensing of evapotranspiration is an evolving and under- utilized technology that offers substantial potential to improve our ability to manage water use within watersheds. Groundwater recharge may provide an effective means to store additional supplies.

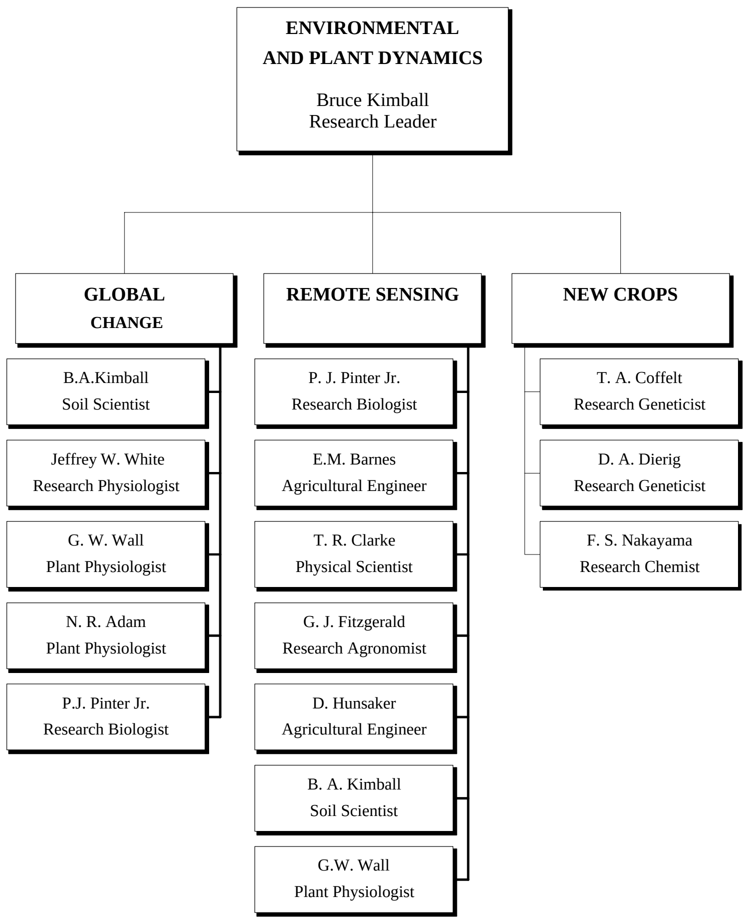
- Improving effectiveness of agricultural water use: Research on irrigation improvements are needed in two areas; the field irrigation systems and the water distribution systems. Field irrigation performance can be substantially improved with modern technology, even in the presence of high water tables and/or high salinity conditions. The research focus will be on surface irrigation where more improvement is possible and where soil variability has more impact. Research on distribution systems will focus on improved operations and canal automation, with the focus of improving service, and thus on-farm efficiency, and reducing losses.

- Managing Water of Impaired Quality: Research studies are needed to determine effective ways to manage saline water supplies and to identify which areas with potential salinity problems are sustainable and which are not. Sustainability includes economic viability. Research is also needed to develop effective management strategies for the reuse of municipal and agricultural-processing wastewater to prevent the movement of various chemicals and pathogens through the soil to groundwater. Irrigation of turf grass can be an effective method for utilizing municipal sewage effluent. The goals are improved utilization of the water resource and improved river water quality.

- Protecting Water Quality: Research is needed to understand how nutrients and trace elements are transported over and through irrigated soils. This is important for developing on-farm management strategies that limit this movement. Development of off-site treatment practices (for example buffer strips) and reduction of off-site impacts also require additional research.
- Reducing negative environmental effects of land retirement: Land retirement can have a negative impact on soil, air and water quality. Research is needed to understand how to manage retired, previously irrigated lands in order to avoid environmental degradation problems such as soil salinization, wind erosion, and increased particulate emissions and damage to neighboring cropped lands.

ENVIRONMENTAL
&
PLANT DYNAMICS
MANAGEMENT UNIT

E&PD Organization



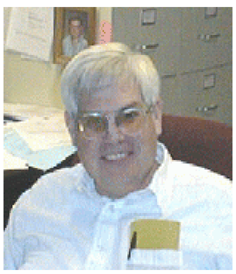
Mission

The Environmental and Plant Dynamics (E&PD) Research Group seeks to develop optimum resource management strategies for meeting national agricultural product requirements within the context of possible changes in the global environment. There are three main research thrusts: The first is predicting the effects of the increasing atmospheric CO_2 concentration and climate change on the yield and water use of crops in the future. The second thrust seeks to improve agricultural water management utilizing remote sensing approaches for observing plant conditions and biophysical processes which are amenable to large scale resource monitoring using aircraft- and satellite-based sensor systems. The third research thrust is to develop new industrial crops with unique high value products and lower water requirements for commercial production within the context of changing environments.

E&PD RESEARCH STAFF

NEAL R. ADAM, B.S., M.S., Ph.D., Plant Physiologist
Research regarding physiological, biochemical and molecular responses of wheat to CO2 enrichment in FACE crop canopy experiment. Establish protocol for enzyme activity assays, SDS-PAGE and other biochemical procedures on leaf samples. Design and implement data collection and processing tools.

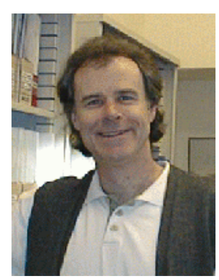
THOMAS R. CLARKE, B.A., Physical Scientist
Remote sensing for farm management, thermal and optical radiometry, and instrument calibration.



TERRY A. COFFELT, B.S., M.S., Ph.D., Research Geneticist-Plants
Breeding, genetics, and germplasm evaluation of new crops--guayule, lesquerella, and vernonia; development of acceptable production practices.

DAVID A. DIERIG, B.S., M.S., Ph.D., Research Geneticist-Plants
Breeding, genetics, germplasm collection and evaluation of new industrial crops with unique, high-value products, including lesquerella, vernonia, and guayule.

GLENN J. FITZGERALD, B.A., M.S., Ph.D., Research Agronomist
Application of geospatial technologies to site specific farming, multispectral and hyperspectral remote sensing for detection and identification of plant stress and anomalies.



DOUGLAS J. HUNSAKER, B.S., M.S., Ph.D., Agricultural Engineer
Effects of soil and irrigation spatial variability on crop water use and yield in large irrigated fields; level basin irrigation design and management procedures for applying light, frequent water applications to cotton; CO2 effects, in particular, of evapotranspiration in the free-air CO2 enrichment (FACE) environment; evaluation of water requirements and irrigation management of

new industrial crops--lesquerella and vernonia.

BRUCE A. KIMBALL, B.S., M.S., Ph.D., Research Leader for E&PD and Supervisory Soil Scientist
Effects of increasing atmospheric CO_2 and changing climate variables on crop growth and water use; free-air CO_2 enrichment (FACE), and CO_2 open-top chambers and greenhouses; micrometeorology and energy balance; plant growth modeling.

FRANCIS S. NAKAYAMA, B.S., M.S., Ph.D., Research Chemist
New crops such as guayule (for latex rubber and resin), lesquerella (hydroxy fatty acid) and vernonia (epoxy fatty acid); including extraction and analytical techniques and by-product uses for the various components; Editor-in-Chief of Industrial Crops and Products, an International Journal.

PAUL J. PINTER, JR., B.S., M.S., Ph.D., Research Biologist
Applications of remote sensing technology to management of agricultural resources and research in plant sciences; effects of elevated CO_2 on biophysical properties of plants.

GERARD W. WALL, B.S., M.S., Ph.D., Plant Physiologist
Derivation of experimental databases to quantify growth, development, and physiological response of agronomic crops to full-season CO_2 enrichment; development of deterministic and stochastic digital simulation models of the soil-plant-atmosphere continuum in response to a CO_2 enriched environment.

JEFFREY W. WHITE, B.S., M.S., Ph.D., Plant Physiologist

Applications of crop growth modeling and geographic information systems in efforts to estimate regional impacts of increasing atmospheric CO_2 and climatic variation; physiology of crop response to temperature and elevated atmospheric CO_2; data management for crop modeling.

AGRICULTURAL PRODUCTIVITY AND WATER USE: EFFECTS OF GLOBAL CHANGE

Bruce A. Kimball, Supervisory Soil Scientist
Gerard W. Wall, Plany Physiologist
Paul J. Pinter, Jr., Research Biologist
Neal R. Adam, Plant Physiologist

PROJECT SUMMARY

We propose to conduct global change research over the next three years with the following objectives: (1) Determine the long-term effects of elevated CO_2 on the physiology, growth, wood production, fruit yield, fruit nutritional quality, and water use efficiency of sour orange trees, as well as its effects on soil structure and carbon. This is a continuation of an ongoing open-top chamber experiment started in 1987, which is the longest such continuous CO_2-enrichment experiment ever conducted. (2) Assess likely impacts of global change on the productivity of agricultural crops via synthesis and integration of existing large accumulated experimental data base plus additional crop growth modeling. (3) Determine effects of elevated CO_2 on the physiology, growth, yield, N_2-fixation, persistence, and soil carbon sequestration of alfalfa using the free-air CO_2 enrichment (FACE) approach. This experiment is the logical follow-on to prior such FACE experiments on cotton, wheat, and sorghum conducted at Maricopa, AZ. (4) Determine effects of elevated CO_2, water supply, and grazing pressure on productivity, shrub-grass competition, carbon sequestration, and water relations of the piñon-juniper rangeland ecosystem, also using the FACE approach. This new project, called Carbon Exchange and Sequestration in Arid Regions (CESAR), would utilize CO_2 from a huge geologic source within this ecosystem, and it would involve a large consortium of universities, ARS, private industry, and others. Achieving Objectives 3 and 4 is contingent upon obtaining outside funding.

OBJECTIVES

1. Determine the long-term effects of elevated CO_2 on the physiology, growth, wood production, fruit yield, fruit nutritional quality, and water use efficiency of sour orange trees, as well as its effects on soil structure and carbon sequestration beneath the trees.

2. Assess likely impacts of potential global change on productivity of agricultural crops via synthesis and integration of large accumulated experimental data bases.

   [Note: Objectives 3 and 4 are contingency plans dependent upon obtaining outside funding.]

3. Determine effects of elevated CO_2 on the physiology, growth, yield, N_2-fixation, persistence, and soil carbon sequestration of alfalfa.

4. Determine effects of elevated CO_2, water supply and grazing pressure on the productivity, shrub-grass competition, carbon sequestration, and water relations of the piñon-juniper rangeland ecosystem.

NEED FOR RESEARCH

Description of the Problem to be Solved

1. Sour orange: Whether enough carbon can be sequestered in the boles of tress and in the soil beneath them to significantly slow the rate of rise of atmospheric CO_2 concentration is an important question facing global change research, as are the implications of the ongoing CO_2 rise for human nutrition. *Sour orange* represents such long-lived woody species, which is being studied to determine (1) whether an initial CO_2-induced enhancement in wood and fruit production will be maintained over a tree's life span, (2) whether quality of wood and fruit will change, and (3) whether increases will occur in soil carbon storage beneath the trees.

2. Synthesis and Integration: Policymakers often have difficulty perceiving principles from the vast array of facts before them, so a common refrain is that the products of scientific research are "data rich and knowledge poor." Currently, about 2 papers are being published every 3 days about the effects of CO_2 and other environmental variables on agricultural crops, from which more definitive knowledge about global change effects on agriculture needs to be synthesized. Furthermore, available assessments may be suspect. The Inter-governmental Panel for Climate Change is now writing its third major assessment of likely impacts of global change on agriculture (as well as many other facets of world society), but most of the predictions are based on simple plant growth models which ignore some important plant processes (IPCC, 2001).

   Four simple models (Tubiello et al., 1999; Jamieson et al., 2001) were able to simulate the responses of wheat to elevated CO_2 interacting with soil water and soil nitrogen supplies as observed in our free-air CO_2 enrichment (FACE) wheat experiments. Nevertheless, such simple models as tabulated by the IPCC (2001) cannot address some important aspects of plant growth responses to elevated CO_2. For example, they "grow" the crops at air temperature rather than at the crop's own temperature; yet, we have shown that elevated CO_2 causes wheat canopies to warm 0.6 to 1.2_C above air temperature due to the direct effects of the elevated CO_2 on the plants' stomatal apertures (Kimball et al., 1992, 1995, 1999). Such warming would be in addition to any global warming of air temperature, and it could cause similar consequences, such as changes in yield and major shifts in optimal production regions of crops. A second effect that is not adequately addressed by simple daily-time-step models is that plants make their photosynthate during daytime, yet they continue to translocate material and grow at night. Therefore, daily temperature patterns may be very important in determining plant responses to elevated CO_2. One prediction of general circulation models is that night temperatures are likely to warm more in the future than daytime temperatures (Collatz et al., 2000; Easterling et al., 1997; Hansen et al., 1995). Therefore, another generation of assessments needs to be done -- with detailed process-oriented models capable of simulating all known effects of elevated CO_2, as well as of other interacting environmental variables, on crop physiology, growth, yield, carbon sequestration, and water relations.

3. Alfalfa: Alfalfa is a perennial deep-rooted legume crop that has the potential to respond to elevated CO_2 with deep sequestration of soil carbon, even at low soil nitrogen and thereby slow the rate of rise of the atmospheric CO_2 concentration. It is an important forage crop in the U.S. (24 million acres; 4th in acreage behind corn, wheat, and soybeans; USDA, 2000) that grows well in Arizona. Specific scientific reasons to focus on alfalfa are: (1) being deep-rooted, alfalfa can sequester carbon at deeper depths below the plow layer where it may be able to be stored for much longer periods, (2) being perennial, alfalfa grows the year around, so the interaction between elevated CO_2 and temperature can be studied, and (3) being a legume, the effects of elevated CO_2 on nitrogen fixation can be examined, as can the importance of nitrogen for C sequestration.

4. Piñon-juniper: Piñon-juniper is an expansive ecosystem whose character may be changed by global change. This vast mid-elevation ecosystem serves as rangeland for substantial cattle production and watershed catchment for much of the Western U.S. It contains more than a dozen National Parks and Monuments, is home to numerous Native American groups, has a history of varied natural resource management (fire suppression, logging, grazing), and is under great development pressure from surrounding regions (Wilkinson 1998). Little research has addressed biosphere-atmosphere interactions of this region, yet paleoecological studies and climate change models indicate this region may be highly sensitive to global change (Cole,1985; Nielson, 1995; Grissino-Mayer et al., 1997). Land use (fire suppression, grazing) has had widespread impacts on this region (Fleischner, 1994; Brown and McDonald, 1995; Moore et al., 1999), yet we do not understand the implications of these activities for C exchange and sequestration, nor the nature of their interaction with atmospheric and climatic change. Insect outbreaks associated with climate change appear to be increasing (Walker et al., 1998). Their impacts on ecosystem C fluxes and sequestration can be significant but are little understood in arid regions. Of the region's major vegetation types, the piñon–juniper woodland is the third most extensive in the continental U.S. Therefore, there are several reasons to determine the effects of elevated CO_2 and other interacting environmental variables on this important ecosystem.

Relevance to ARS National Program Action Plan

The project is relevant to all components. While the primary emphasis is on determining and assessing the impact of global change on *agricultural ecosystems* and to develop strategies for adaptation, this research inherently involves studying all aspects of *carbon cycling* from photosynthetic carbon assimilation to soil carbon sequestration, the latter of which can mitigate the rate of global change. Production of *trace gases*, such as N_2O, will also be addressed. In addition, the influences on surface energy balance and evapotranspiration will be assessed, thereby contributing to the *water cycle* component.

Potential Benefits

The main benefit will be an enhanced ability to prepare for potential global change. Knowing the probable impacts of global change on crop production and water use in each region will give researchers and growers the incentive to develop strategies for coping with problems and maximizing benefits, as well as for sequestering carbon to mitigate the rate of global change. The growth models developed as part of this research should prove to be useful tools for developing such strategies.

Anticipated Products

Scientific publications will be produced that describe, as well as synthesize and integrate, the effects of elevated CO_2 and interacting environmental variables on plant physiology, growth, yield, light use efficiency, carbon sequestration, and water use of crops and rangeland for various regions and global change scenarios. Process-based plant growth models that have been more perfected and validated than currently exist will also be products of this research.

Customers

Other agencies, such as the Department of Energy and Environmental Protection Agency, need the information to set policy regarding carbon storage credits, energy sources (i.e., coal versus nuclear), CO_2 emissions (whether to tax or not), and land use (reforestation). Agricultural policymakers will also use the information to formulate resource conservation plans for the next Farm Bill, especially if there is a "green payments" program that encourages carbon sequestration. And, of course, farmers eventually will use the information.

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

	Research Objective or Area of Study			
Date	**1. Sour Orange Trees (Idso, Kimball)**	**2. Synthesis & Integration (Kimball, Idso, Wall, Pinter)**	**3. FACE Alfalfa Expt. (Kimball, Wall, Pinter)**	**4. FACE Piñon-Juniper Rangeland Expt. (Kimball, Wall, Pinter)**
Jan. 2001	Harvest fruit & tabulate monthly growth increments for 2000.	Review of free-air CO_2 enrichment (FACE) effects on agricultural crops completed.	Proposal submitted to NASA for funding.	Rough plan and pre-proposal completed.
Jan. 2002	Ditto for 2001 + folic acid production + soil fungal growth & glomalin & soil structure.	Above FACE review published, and review of carbon sequestration completed. Paper on elevated CO_2 effects on canopy temperature and crop production areas written.	If selected for NASA funding, will install FACE apparatus and plant alfalfa in fall 2001. If not, then timetable will pushed forward accordingly until funding finally achieved.	Second stage planning completed, and proposal prepared and submitted to funding agency.
Jan. 2003	Ditto for 2002 + wood density & strength + water use efficiency.	First regional study with *ecosys* on wheat completed. Paper written on relationship between radiatio use efficiency and CO_2 concentration.	Tabulation and review of first year's growth, remote sensing, energy and water balance, photosynthesis and water relations, and other data.	If selected for funding, initiate experiment in spring of 2002. If not, timetable will be delayed accordingly until funding finally achieved.
Jan. 2004	Ditto for 2003 + differing sunlit & shaded growth & fruit & antioxidant + history of leaf starch & sugar production + leaf senescence & fall history.	First regional study with *ecosys* on sorghum completed. Cotton model selected and regional study intiated.	Tabulation and review of second year's growth, remote sensing, energy and water balance, photosynthesis and water relations, and other data.	Tabulate and review of initial season's baseline measurements at ambient CO_2.
Mar. 2004	End of time for this proposed project plan.			
Jan. 2005	Ditto for 2004. This marks the minimum length of time to be sure that the CO_2-enriched trees have achieved a constant relative growth advantage over the ambient-treatment trees (Figure 1) that can reasonably be expected to continue throughout the remaining life of the trees.		Tabulation and review of third year's growth, remote sensing, energy and water balance, photosynthesis and water relations, and other data. Papers written on these topics.	FACE treatment starts spring of 2004. Tabulation and review of first season's growth, remote sensing, energy and water balance, photosynthesis and water relations, and other data.

PROGRESS

In order to determine the likely effects of the increasing atmospheric CO_2 concentration on future evapotranspiration (ET, water use), ARS scientists from the U.S. Water Conservation Laboratory, Phoenix, AZ, and cooperators from the University of Arizona (including J.M. Triggs, T.J. Brooks, M.J. Ottman, A.D. Matthias, S.W. Leavitt) and Arizona State University (R.S. Cerveny) exposed plots of field-grown sorghum at Maricopa, AZ, to concentrations of 550 ppm CO_2 (or 200 'mol/mol above current ambient levels of about 360 'mol/mol) using a free-air CO_2 enrichment (FACE) facility. Data were collected for two growing seasons at ample and limiting supplies of water, with ET being determined using an energy balance approach. The FACE treatment decreased ET about 12% at ample water with little effect on yield, whereas when water was limited, FACE stimulated yields about 15%, but had little effect on water use. Therefore, provided impacts of possible climate change are not too severe, the water requirements for irrigated sorghum are likely to decrease in the future with little change in productivity, whereas, for rain-fed water-stressed sorghum, yields are likely to increase for the same amount of water.

The rising atmospheric CO_2 concentration is predicted to cause global warming and altered precipitation patterns, which could increase the likelihood of high-temperature extremes and increased frequency and severity of droughts, thereby affecting plant water status and subsequent photosynthesis and yield of crops, including wheat, the world's foremost grain source. Therefore, ARS researchers from the U.S. Water Conservation Laboratory, Phoenix, AZ, in cooperation with scientists from several other research groups around the world, using free-air CO_2 enrichment (FACE) technology, grew wheat at elevated CO_2 concentrations such as expected later this century (550 ppm) under well-watered and drought conditions. Compared with control plots at ambient CO_2, FACE increased photosynthetic rates by 32% at mid-morning, 25% at midday, and 23% at mid-afternoon under the well-watered conditions, whereas under drought, FACE increased the photosynthetic rates by only 7% at mid-morning and mid-day, but by as much as 35% at mid-afternoon. Hence, in a future high-CO_2 world, improved water relations and consequent higher photosynthetic rates are anticipated for wheat and similar crops, especially during mid-afternoons when drought conditions have their most deleterious effects on physiological processes.

Understanding how slow-growing perennial trees will be affected by future increasing levels of carbon dioxide after a period of years or decades is crucial to understanding the future impact of global change. Photosynthesis and biomass production have been monitored by ARS Scientists from the U.S. Water Conservation Laboratory, Phoenix, AZ, and a cooperator from Arizona State University (Andrew Webber) on well-fertilized sour orange trees growing under an enhanced carbon dioxide atmosphere for 14 years. Over this time span, the CO_2-induced enhancement of annual wood biomass increment declined from 184% to 78%, whereas the enhancement of photosynthesis declined from 184% in 1991 (second year) to 28% in 2001, and the photosynthetic decrease was shown to be due to a decrease in the content of the primary CO_2-fixing enzyme. This enzyme reduction represents a decrease in the capacity for photosynthesis even when nitrogen is non-limiting, which is information that is useful to ecological modelers for predicting long-term effects of elevated CO_2 on the growth of trees in the future.

The Earth's atmospheric carbon dioxide (CO_2) concentration is predicted to double by the end of this century, which likely will stimulate the photosynthesis of so-called C3 plants (which includes most plant species) but not so-called C4 plants (such as corn and sorghum). In spite of relatively little photosynthetic response to elevated CO_2, nevertheless, there are a number of recent scientific reports indicating that growth under elevated CO_2 concentrations enhances C4 crop productivity. To test whether the enhanced productivity could be in part due to C3 photosynthesis in young leaves where the C4 photosynthetic function is not fully developed, ARS scientists from the U.S. Water Conservation Laboratory, Phoenix, AZ and cooperators from Arizona State University (A.B. Cousins and A.N. Webber) and the University of Arizona (M.J. Ottman, S.W. Leavitt and others) determined the cellular anatomy and biochemical processes in young sorghum leaves grown in the field under free-air CO_2 enrichment (FACE). The results showed the progression of C3 to C4 function, but by the time the leaves emerged to full sunlight from their encasing whorl, the C4 apparatus was fully functional, which means that alternative explanations must be found to understand how elevated CO_2 affects sorghum growth.

The CO_2 concentration in the atmosphere is increasing and has been predicted to cause global climate change. In order to predict the likely effects of the elevated CO_2 and any associated climate change on future wheat productivity, three wheat growth simulation models were tested by scientists from the Royal Veterinary and Agricultural University, Taastrup, Denmark (F. Ewert); Wageningen University, Wageningen, The Netherlands (D. Rodriguez); New Zealand Institute for Crop and Food Research, Christchurch, New Zealand (P. Jamieson); and others. They were tested against wheat growth data obtained using free-air CO_2 enrichment (FACE) technology in open-field plots by University of Arizona scientists and ARS scientists from the U.S. Water Conservation Laboratory, Phoenix, AZ. The models (called AFRCWHEAT2, LINTULCC2, and SIRIUS) have varying levels of detail in their handling of physiological processes, yet most model results were acceptably close to observed values, which greatly strengthens our confidence in the use of such models in assessments of future wheat productivity.

It has recently been demonstrated that near-surface atmospheric CO_2 concentrations in large cities may be substantially higher than those of surrounding rural areas, and it has been suggested that this phenomenon may provide a natural laboratory for studying the effects of atmospheric CO_2 enrichment on plant growth and development. To assess the potential of this concept, an ARS scientist from the U.S. Water Conservation Laboratory, Phoenix, AZ, and cooperators from Arizona State University (C.D. Idso and R.C. Balling) measured atmospheric CO_2 concentrations in a residential sector of the urban CO_2 dome of Phoenix, Arizona at one-minute intervals for most of an entire year. They found that the mean daytime CO_2 concentrations 21 km from the center of the city, but still within the metropolitan area and close to its two major freeways, were only 10% greater than values characteristic of rural air. Therefore, any research program designed to capitalize upon the range of CO_2 concentrations provided by a city's urban CO_2 dome would have to be established close to the center of the metropolitan complex in order to provide meaningful experimental treatments, but unfortunately, this requirement might introduce confounding effects due to higher levels of noxious air pollutants that may exist near the city center.

The CO_2 concentration of Earth's atmosphere continues to rise, and although many experiments have demonstrated that trees grow bigger and faster when exposed to air of higher CO_2 content, few have examined the quality of the wood they produce. Hence, ARS scientists from the U.S. Water Conservation Laboratory, Phoenix, AZ, measured the effects of a 75% increase in the air's CO_2 concentration (a rise from 400 to 700 parts per million) on the density of the wood produced in the branches of sour orange trees. They found a modest increase of approximately 5.8%, which translates into increases of 4.8 to 13.5% in a number of valued wood properties, and, in addition, the density of the wood produced in the branches of the CO_2-enriched trees was more uniform than that of the wood produced in the branches of trees growing in normal-CO_2 air. These findings suggest that the quality of wood products should improve in the future.

Elevated levels of CO_2 stimulate plant photosynthesis and also cause a partial closure of the stomata in plant leaves through which the plant exchanges CO_2 and water vapor with the atmosphere. In order to predict what effect the elevated CO_2 will have on future crop productivity and to aid in developing improved management strategies, crop growth simulation models are being developed by scientists (P. Manunta, R.F. Grant, and Y. Feng) from the University of Alberta, Edmonton, Canada, which incorporate a new approach to simulating stomatal controls on mass (water vapor and CO_2) and energy transfer between crop canopies and the atmosphere. A successful test of the model was conducted utilizing results of an experiment conducted by ARS scientists from the U.S. Water Conservation Laboratory, Phoenix, AZ, and cooperators from the University of Arizona whereby open-field-grown wheat was exposed to elevated levels of CO_2 using free-air CO_2-enrichment (FACE) technology at ample and limited levels of soil water. Both measured and simulated values of water use were reduced by about 6% at ample water and by about 2% when water was limited due to elevated CO_2 concentrations of 550 ppm (such as expected near the middle of this century), which indicates irrigation water requirements will be decreased slightly due to the elevated CO_2 in the future and that we can have greater confidence in the model for assessing future impacts of global change.

The capability to remotely distinguish late season frost damage from normal crop senescence is important for predicting crop yields and assessing damage for crop insurance purposes. ARS researchers from the U.S. Water Conservation Laboratory in Phoenix, AZ in collaboration with scientists from the University of Arizona, characterized the reflectance properties of grain sorghum grown for two seasons under Free Air Carbon dioxide Enrichment (FACE) at the Maricopa Agricultural Center in central Arizona. Field and laboratory evidence revealed changes in spectral properties and vegetation indices that were uniquely related to frost injury and also related to the degree of injury experienced by plants in the different CO_2 and irrigation treatments. Results suggest feasible methods for determining the extent of frost damage to the crop under typical field conditions that could be used over wide areas to evaluate losses.

A rapid method to excise uniform plant parts for further study from a plant was needed that would minimize damage to both the plant part in order to maintain shelf life and to the remaining plant in order for it to continue healthy growth. Therefore, an ARS researcher from the U.S. Water Conservation Laboratory, Phoenix, AZ, in cooperation with an undergraduate student (G. McDonnell) from Arizona State University developed a Rapid Excision Apparatus for Plants (REAPer). Preliminary testing of the REAPer proved that it can rapidly excise a plant part with minimal mechanical damage to xylem elements, and moreover, the cuts are more uniform, which helps standardize the process. The REAPer will not only aid in research, but it also has commercial application in both the horticultural and floral industries as well.

Publications:

Adam, N.R., and Wall, G.W. Multi-purpose cryogenic surface device. 2002. U.S. Patent 6,418,750.

Conley, M.M., Kimball, B.A., Brooks, T.J., Pinter, P.J.Jr., Hunsaker, D.J., Wall, G.W., Adam, N.R. LaMorte, R.L., Matthias, A.D., Thompson, T.L., Leavitt, S.W., Ottman, M.J., Cousins, A.B., and Triggs, J.M. CO_2 enrichment increases water use efficiency in sorghum. New Phytologist. 2001. 151(2): 407-412.

Hatfield, J.L., and Kimball, B.A. Future research to fill knowledge gaps. In Agricultural System Models in Field Research and Technology Transfer. Lewis Publishers. 2002. p. 331-344.

Idso, S.B. and Kimball, B.A. CO_2 enrichment of sour orange trees: 13 years and counting. Environmental and Experimental Botany. 2001. 46(2):147-153.

Idso, S.B., Kimball, B.A., Shaw, P.E., Widmer, W., Vanderslice, J.T., Higgs, D.J., Montanari, A., and Clark. W.D. The effect of elevated atmosphric CO_2 on the Vitamin C Concentration of (sour)orange juice. Agriculture, Ecosystems, & Environment. 2002. 90:1-7.

Kimball, B.A., Kobayashi, K., and Bindi, M. Responses of agricultural crops to free-air CO_2 enrichment. Advances in Agronomy. 2002.77:293-368.

Kimball, B.A., Triggs, J.M., Pinter, P.J.Jr., Wall, G.W., Ottman, M.J., Leavitt, S.W., Matthias, A.D., and Brooks, T.J. Free-air CO_2 enrichment of sorghum: energy balance and evapotranspiration. Annual Meetings Abstracts. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI. CD ROM. 2002. File a03-Kimball130125-P.

Pendall, E., Leavitt, S.W., Brooks, T., Kimball, B.A., Pinter, P.J.Jr., Wall,, G.W., LaMorte, R.L., Wechsung, G., Wechsung, F., Adamsen, F., Matthias, A.D, and Thompson, T.L. Elevated CO_2 stimulates soil respiration and decomposition in a FACE wheat field. Basic Applied Ecology. 2001. 2:193-201.

Wall, G.W., Kimball, B.A., Adamsen, F.J., Pinter, P.J.Jr., Wechsung, G., Wechsung, F., Kartschall, Th., and Leavitt, S.W. Elevated atmospheric carbon dioxide affects root dimensions of spring wheat. Annual Meetings Abstracts. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI. CD ROM. 2002. File a03-Kimball150553-P.

Wall, G.W. Elevated atmospheric CO_2 alleviates drought stress in wheat. Agriculture, Ecosystems and Environment. 2001. 261-271.

Wall, G.W., Brooks, T.J., Adam, N.R., Cousins, A.B., Kimball, B.A., Pinter, P.J.Jr., LaMorte, R.L., Triggs, J., Ottman, M.J., Leavitt, S.W., Matthias, A.D., Williams, D.G., and Webber, A.N. Elevated atmospheric CO_2 improved sorghum plant water status by ameliorating the adverse effects of drought. New Phytologist. 2001. 152:231-248.

IRRIGATED CROP MANAGEMENT UTILIZING REMOTE SENSING

Paul J. Pinter, Jr., Research Biologist
Edward M. Barnes, Agricultural Engineer
Glenn J. Fitzgerald, Research Agronomist
Thomas R. Clarke, Physical Scientist
Douglas J. Hunsaker, Agricultural Engineer
Bruce A. Kimball, Supervisory Soil Scientist
Floyd J. Adamsen, Soil Scientist
Gerard W. Wall, Plant Physiologist

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

<table>
<tr><th rowspan="2">Date</th><th colspan="3">Research Objective or Area of Study</th></tr>
<tr><th>1. Crop Response</th><th>2. Irrigation Scheduling</th><th>3. Precision Agriculture</th></tr>
<tr><td>Oct. 2001</td><td colspan="3">Scheduled Starting Time for Project</td></tr>
<tr><td>Jan. 2002</td><td>_ 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)</td><td>_ 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)</td><td>_ 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.</td></tr>
<tr><td>Jan. 2003</td><td>_ 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</td><td>_ 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</td><td>_ Growth, yield, and water content from cotton field experiment used to validate prec ag approach using cotton model.</td></tr>
<tr><td>Jan. 2004</td><td>_ Paper on use of CCCI or comparable index for monitoring N stress in wheat written and submitted to Journal. (Clarke, Pinter)</td><td>_ 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)</td><td>_ 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.)</td></tr>
<tr><td>Jan 2005</td><td>_ 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)</td><td>_ 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)</td><td>_ Paper on techniques for incorporating RS into cotton growth model written and submitted to journal. (Barnes, et al.)</td></tr>
<tr><td>Jan 2006</td><td>_ Data analysis, publication, and presentation of results as significant outcomes arise. (All)</td><td>_ 2nd wheat experiment completed (May 2005), data reduced, tabulated, and analyzed (All)
_ Publication and presentation of results (All)</td><td>_ Data analysis, publication, and presentation of results as significant outcomes arise.</td></tr>
<tr><td>Sept. 2006</td><td colspan="3">End of Proposed Project Plan</td></tr>
</table>

PROGRESS:

Methods for estimating daily crop water use were recently published by the Food and Agriculture Organization of the United Nations and are expected to become the de facto standard for irrigation approaches used by farmers, consultants, and governmental water resource agencies. ARS researchers from the U.S. Water Conservation Laboratory evaluated these methods (referred to as FAO-56 procedures) for estimating daily water requirements of alfalfa grown throughout the year under irrigation in the arid southwestern U.S. Using local micrometeorological inputs and information on stage of growth, the FAO-56 estimates matched daily alfalfa crop water usage closely and validated it's use for irrigation scheduling in an arid region. Slight modification of the procedure can help growers and water planners attain even more accurate estimates of water use.

Agriculture has benefited in many ways from the remote sensing research conducted over the past 4 decades by ARS scientists and their partners in the university system, NASA, and other government agencies. Researchers from the U.S. Water Conservation Laboratory in Phoenix, AZ along with colleagues from a number of different ARS locations prepared four manuscripts that were included within a special issue of the scientific journal Photogrammetric Engineering and Remote Sensing. These review articles examined Agricultural Research Service contributions by emphasizing historical aspects of remote sensing research, applications of remote sensing for mapping soil properties and crop management, and progress in sensor development and radiometric correction. This collection of papers shows the importance of ARS research contributions to agriculture and suggests the directions for future agricultural remote sensing efforts.

Quantitative methods for determining crop phenology and reproductive effort are often required for effective timing of certain management practices, such as irrigation, fertilization, and harvest. ARS scientists from the U.S. Water Conservation Laboratory in Phoenix, AZ developed an efficient and cost effective method of estimating flower number from images obtained with a color digital camera. This new method was applied to a Lesquerella crop grown under irrigated conditions in Arizona and revealed that knowledge of flowering rates should improve production efficiency through changes in timing of water and fertilizer applications. These results will be of value to researchers, consultants, and farm managers who are interested in obtaining lesquerolic acid from Lesquerella seeds for use as a castor oil replacement in commercial greases, cosmetics, polishes, inks, and coatings.

The capability to remotely distinguish late season frost damage from normal crop senescence is important for predicting crop yields and assessing damage for crop insurance purposes. ARS researchers from the U.S. Water Conservation Laboratory in Phoenix, AZ in collaboration with scientists from the University of Arizona, characterized the reflectance properties of grain sorghum grown for two seasons under Free Air Carbon dioxide Enrichment (FACE) at the Maricopa Agricultural Center in central Arizona. Field and laboratory evidence revealed changes in spectral properties and vegetation indices that were uniquely related to frost injury and also related to the degree of injury experienced by plants in the different CO2 and irrigation treatments. Results suggest feasible methods for determining the extent of frost damage to the crop under typical field conditions that could be used over wide areas to evaluate losses. Remotely-sensed plant stress indices hold considerable promise for more efficient application of water and nutrients via sprinkler irrigation systems and variable application rate equipment used in precision agriculture. In collaboration with students and faculty at the University of Arizona, ARS scientists at the U.S. Water Conservation Laboratory made regular measurements of cotton canopy reflectance and temperature during several growing seasons. The studies defined appropriate spatial scales at which measurements need to be taken and demonstrated a new approach for combining the crop water stress index based on plant canopy temperatures with traditional methods of predicting crop water use to indicate how much water is required at each irrigation event. Findings will be of interest to commercial providers of remote sensing imagery and will allow growers to adjust irrigation and fertilizer amounts to match crop needs more closely.

We have initiated the second year of a comprehensive field study to determine whether remotely sensed, multispectral vegetation indices such as the NDVI, can provide reliable estimates of cotton crop coefficients for determining water use and scheduling irrigations in cotton. The current study compares the standard FAO-56 irrigation scheduling approach with an NDVI-based strategy across 3 plant populations and 2 levels of nitrogen fertilization. Experimental protocol includes 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 properties, and insect behavior. Remote techniques are expected to improve daily evapotranspiration estimates via real-time feedback of crop response as influenced by local atmospheric conditions and spatial variation in soil properties, stand density, nutrient availability, and crop development.

Publication(s):

Adamsen, F. J., T. A. Coffelt, and J. M. Nelson. Flowering and seed yield of Lesquerella as affected by nitrogen fertilization and seeding rate. Industrial Crops and Products 2003 v. 18:125-131.

Barnes, E. M., K. A. Sudduth, J. W. Hummel, S. M. Lesch, D. L. Corwin, C. Yang, C. S. T. Daughtry, and W. C. Bausch. Remote- and ground-based sensor techniques to map soil properties. Photogrammetric Engineering and Remote Sensing 2003 v. 69(6): 619-630.

Colaizzi, P. D., E. M. Barnes, T. R. Clarke, C. Y. Choi, and P. M. Waller. Estimating soil moisture under low frequency irrigation using the CWSI. ASCE J of Irrigation and Drainage 2003 v. 129:27-35.

Colaizzi, P. D., E. M. Barnes, T. R. Clarke, C. Y. Choi, P. M. Waller, J. Haberland, and M. Kostrzewski. Water stress detection under high frequency irrigation with Water Deficit Index. American Society of Civil Engineers Journal of Irrigation and Drainage 2003 v. 129:36-43.

Fitzgerald, G. J. Detecting spider mite damage in cotton through spectral mixture analysis of AVIRIS imagery. 2002 v. 75-81. In Proceedings of the 11th JPL Airborne Earth Science Workshop, Pasadena, California, March 5-8, 2002.

Hunsaker, D. J., P. J. Pinter Jr., and H. Cai. Alfalfa basal crop coefficients for FAO-56 procedures in the desert regions of the southwestern U.S. Trans of the ASAE 2002 v. 45(6): 1799-1815.

Kostrzewski, M., P. Waller, P. Guertin, J. Haberland, P. Colaizzi, E. Barnes, T. Thompson, T. Clarke, E. Riley, and C. Choi. Ground-based remote sensing of water and nitrogen stress. Transactions American Society of Agricultural Engineers 2003 v. 46(1):29-38.

Liu, W. Z., D. J. Hunsaker, Y. S. Li, and G. W. Wall. Interrelations of yield, evapotranspiration, and water use efficiency from analysis of water production functions. Agricultural Water Management 2002 v. 56:143-151.

Manunta, P., R. F. Grant, Y. Feng, B. A. Kimball, Pinter Jr., P.J., R. L. LaMorte, D. J. Hunsaker, and G. W. Wall. Changes in mass and energy transfer between the canopy and the atmosphere: model development and testing with a free-air CO2 enrichment (FACE) experiment. Journal of Biometeorology 2002 v. 46: 9-21.

Pinter Jr., P. J., J. L. Hatfield, J. S. Schepers, E. M. Barnes, M. S. Moran, C. S. Daughtry, and D. R. Upchurch. Remote sensing for crop management. Photogrammetric Engineering and Remote Sensing 2003 v. 69(6): 647-664.

Pinter Jr., P. J., J. C. Ritchie, J. L. Hatfield, and G. F. Hart. The Agricultural Research Service's remote sensing program: An example of interagency collaboration. Photogrammetric Engineering and Remote Sensing 2003 v. 69(6): 615-618.

Sadler, E. J., E. M. Barnes, W. D. Batchelor, J. Paz, and A. Irmak. Addressing spatial variability in crop model applications. 2002 v. 253-264. Ahuja, L. R., Liwang, M., and Howell, T. A. Lewis Publishers (ed.) In Agricultural System Models in Field Research and Technology Transfer CRC Press.

Pinter Jr., P. J., G. J. Fitzgerald, B. A. Kimball, G. W. Wall, M. J. Ottman, R. R. Rokey, and S. M. Maneely. Frost-induced changes in spectral characteristics of grain sorghum. Agronomy Abstracts 2002 CD-Rom A03-Pinter163003-O

Moran, M. S., G. J. Fitzgerald, A. Rango, C. L. Walthall, E. D. Barnes, W. C. Bausch, T. R. Clarke, C. S. Daughtry, J. H. Everitt, J. L. Hatfield, K. M. Havstad, T. J. Jackson, N. R. Kitchen, W. P. Kustas, M. R. Mcguire, P. J. Pinter Jr., K. A. Sudduth, J. S. Schepers, T. J. Schmugge, P. J. Starks, and D. R. Upchurch. Sensor development and radiometric correction for agricultural applications. Photogrammetric Engineering & Remote Sensing 2003 v. 69:705-718.

Hunsaker, D. J., E. M. Barnes, T. R. Clarke, B. A. Kimball, G. J. Fitzgerald, J. C. Silvertooth, J. R. Hagler, and P. J. Pinter Jr. Combining remotely-sensed crop coefficients with the FAO-56 irrigation scheduling procedures. Agronomy Abstracts 2002 CD-Rom A03-Hunsaker205300-P.

Kimball, B. A., J. M. Triggs, P. J. Pinter Jr., G. W. Wall, M. J. Ottman, S. W. Leavitt, A. D. Matthias, and T. J. Brooks. Free-air CO2 enrichment of sorghum: energy balance and evapotranspiration. Agronomy Abstracts 2002 CD ROM a03-Kimball130125-P.

GERMPLASM IMPROVEMENT
AND
AGRONOMIC DEVELOPMENT
OF
NEW ALTERNATIVE CROPS

Terry A. Coffelt, Research Geneticist
David A. Dierig, Research Geneticist
Francis S. Nakayama, Research Chemist

PROJECT SUMMARY

Agricultural diversification is important for achieving economic stability and future growth of agriculture. One way to achieve diversification is the development of new crops. New/alternative crops must complement instead of compete with existing traditional crops. In addition, the new crops must be able to conserve water and nutrients and help in improving the environment. The objectives of this project are to (1) acquire and characterize germplasm of promising new/alternative crops; (2) evaluate and enhance new crop germplasm for industrial materials; (3) develop basic knowledge of floral biology, seed production, and plant responses to environmental stresses; (4) develop economical production systems for new crops under various environmental and management conditions; and (5) develop methods for efficient guayule latex extraction and seed oil analyses for characterizing latex, resin, and oil properties. This research will result in scientific and popular publications on the basic biology, characteristics, production systems, and methodology for evaluating, enhancing, and growing new crops. The long-term goal is to provide high yielding germplasm of new crops that is adaptable to a variety of environments and has materials needed for industrial uses. This CRIS is the lead USDA-ARS project for breeding, genetics, germplasm collection, germplasm evaluation, and germplasm enhancement of new crops, and is the major source of the raw materials needed for pursuing related work on product development and utilization. The development of guayule as a new crop would provide relief to the 6 % of the US population with allergies to Hevea latex products. This includes 40 % of the medical workers and 60 % of multiple surgery cases. It would also develop a domestic source of latex, reducing our dependence on imported rubber. Development of additional products from the bagasse could result in additional products such as insulation, termite and wood rot resistant wood products, and a new natural gum base to use in chewing gums. Development of lesquerella as a new crop would result in a domestic source of hydroxy fatty acid, replacing castor oil imports that cost over $100 million annually. The oil would serve as base for renewable based lubricating oils.

OBJECTIVES

1. Acquire and characterize germplasm of guayule, lesquerella, vernonia, and other promising new/alternative crops.

2. Evaluate and enhance germplasm of new crops for industrial materials.

3. Develop basic knowledge of floral biology, seed production and plant responses to environmental stresses.

4. Develop economical production systems for new crops under various environmental and management conditions.

5. Develop methods for efficient guayule latex extraction and seed oil analyses for characterizing latex, resin, and oil properties.

NEED FOR RESEARCH

Description of the Problem to be Solved

The need exists for improving the economic status of the U.S. farmer and reducing the costs associated with surplus crops. In addition, improving this country's balance of payment and decreasing its vulnerability to imports of strategic industrial raw materials cannot be readily dismissed. Successful commercialization of the new crops may even lead to the export of the raw and finished products. Agricultural diversification is important for achieving economic stability and future growth of agriculture. New/alternative crops must complement instead of compete with existing traditional crops. In addition, the new crops must be able to conserve water and nutrients and help in improving the environment.

The U.S. spends over one billion dollars annually importing Hevea rubber - the only source of natural rubber for use in industry and commerce. More recently, it was discovered that a large portion of the world population has become allergic to the Hevea rubber hygienic products. These allergies can sometimes be life-threatening. Guayule (*Parthenium argentatum*) synthesizes latex rubber, which has been found to be hypoallergenic and offers an alternative to Hevea latex. Since the plant is native to the southwestern United States, cultivation of this crop could mean additional economic sources for the farmers in this region. Successful commercialization of guayule, however, depends on the identification and development of acceptable production practices and processing methods. While much is presently known about maximizing solid rubber production, little is known about maximizing latex production.

The U.S. imports over 40 million dollars of castor oil, a strategic raw material, annually for use in lubricants, cosmetics, plasticizers, protective coatings, surfactants, and pharmaceuticals. Production of castor in the U.S. is restricted because of its high level of allergic reactions and seed toxicity. Lesquerella (*Lesquerella fendleri*), a plant native to the U.S., produces a hydroxy fatty acid, which is an acceptable alternative to castor oil. Successful commercialization of lesquerella depends on the identification and development of enhanced germplasm with high seed yields, high oil content, high lesquerolic acid content, autofertility, and acceptable production practices. A large germplasm collection is being developed and evaluated for desirable characteristics at the U.S. Water Conservation Laboratory. Much work remains to be done to finish the evaluation of the collection and to transfer the desired traits into commercially acceptable lines. Information is also needed on optimizing production practices.

The oil-based paint and pesticide industries are looking for ways to reduce emissions of volatile organic compounds (VOC), which contribute to the pollution of the atmosphere. One alternative to correct this problem is to use vegetable oils high in epoxy fatty acids. Vernonia (*Vernonia galamansis*) is one of the few plants that naturally synthesizes an epoxy fatty acid, which has low volatility and good solvent properties needed in paints. Other industrial uses for the oil are in epoxy-alkyd paints, toughened epoxy resins, dibasic acids, lubricants, pesticides, and adhesives. Successful commercialization of vernonia depends on the development of germplasm with high yield and oil content, high vernolic acid content, good seed retention, uniform maturity, day neutral flower induction as well as acceptable crop production features.

Information available on the cultural management of these new crops is incomplete. Thus, additional work must be done to obtain answers before wide-scale commercial production is possible. Some examples of areas needing work are dates of planting for maximum stand establishment and yield, seeding rates that are economical, seed treatments to ensure stands and break dormancy, planting methods that result in acceptable stands and result in maximum yields, dates of harvest for maximum yield and quality, harvesting methods that result in minimum losses, water use data for scheduling irrigations, nutrient requirements that minimize pollution and result in high yields, pest control measures for insect, disease, and weed problems, post-harvest and preprocessing studies to maximize yields and quality.

Relevance to ARS National Program Action Plan

This research involves collecting, evaluating, and enhancing germplasm of new crops, while developing planting, growing, and harvesting systems for producing a profitable crop, which contributes to the Plant Germplasm Conservation and Development National Program. Cooperative research with other scientists leads to commercial and industrial applications for new crops and new analytical methods necessary for making progress in a breeding program. Besides the primary uses of these crops, additional products such as gums, bagasse, resins, and seed meals for animal feed contribute to the New Uses National Program 306.

Potential Benefits

The development of guayule as a new crop would provide relief to the 6 % of the US population with allergies to Hevea latex products. This includes 40 % of the medical workers and 60 % of multiple surgery cases. It would also develop a domestic source of latex, reducing our dependence on imported rubber. Development of additional products from the bagasse could result in additional products such as insulation, termite and wood rot resistant wood products, and a new natural gum base to use in chewing gums. Development of lesquerella as a new crop would result in a domestic source of hydroxy fatty acid, replacing castor oil imports that cost over $100 million annually. The oil would serve as base for renewable based lubricating oils.

Anticipated Products

This research will result in scientific and popular publications on the basic biology, characteristics, production systems, and methodology for evaluating, enhancing, and growing new crops. The long-term goal is to provide high yielding germplasm of new crops that is adaptable to a variety of environments and has materials needed for industrial uses.

Customers

Customers of this research include other scientists, cooperative state extension personnel, regulatory agencies, growers, users of the GRIN system, other federal agencies, and industry.

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

This project is scheduled for formal review in 2002, thus only three-year milestones and expected outcomes are listed.

Date	Objective 1	Objective 2	Objective 3	Objective 4	Objective 5
January 2002	New lesquerella germplasm from Mexico will be obtained and seed increased	Guayule germplasm lines will be evaluated for latex and growth	Environmental effects on guayule will be determined	New studies on water use for guayule will be started	Effects of different surfactants on latex extraction will be established
January 2003	New lesquerella germplasm from the US and Mexico will be obtained, evaluated, and seed increased for GRIN system	New lesquerella germplasm lines will be released with higher oil yields	Production system guidelines for lesquerella will be released to growers	Harvesting guidelines for lesquerella will be developed and made available to growers	New products for lesquerella oil will be developed and tested in cooperation with a commercial partner
January 2004	New vernonia germplasm will be released	New higher yielding and faster growing guayule germplasm lines will be released	Production system guidelines for guayule will be released to growers	Production system guidelines for guayule will be developed and made available to growers	New products from guayule bagasse will be developed in cooperation with industry

PROGRESS:

Timing of irrigation and fertilization has not been fully developed for lesquerella, which can be used to replace imported Castor oil in lubricants, coatings, cosmetics and other industrial uses. ARS Researchers at Phoenix, Arizona in cooperation with Researchers at the University of Arizona used an automated method of estimating flower number from digital images to determine the effects of irrigation and fertilization on lesquerella flowering and yield. Flowering data indicated that changes in timing of fertilizer application and irrigation frequency and amounts should improve production efficiency of lesquerella. These research results will be of value to researchers, consultants, and farm managers in optimizing fertilizer and irrigation applications as well as assisting plant modelers in developing better growth models for lesquerella, and plant breeders in developing new higher yielding germplasm.

New sources of renewable energy are needed to reduce our dependence on fossil fuels. Pellet fuel was made by blending guayule bagasse and cotton gin trash by ARS Researchers at Phoenix, Arizona working in cooperation with the ARS Researchers at Lubbock, TX as an alternate source of energy from waste plant materials. Preliminary analysis shows that this combination has good burning and energy properties. Guayule and cotton waste made into fuel pellets could be used in commercially available stoves and heaters designed to burn pelletized solid fuel, thus reducing our dependence on non-renewable energy sources.

Salt tolerance in lesquerella is important to allow production areas to expand. ARS Researchers at Phoenix, Arizona, grew a salt tolerant variety, WCL-SL1, jointly released by ARS Researchers at Phoenix, Arizona and Riverside, California, at sites in Mexico, Texas, and Arizona in cooperation with Researchers from Texas A&M University, the University of Arizona, and Universidad Autonoma Agraria Antonio Narro (Project No. 5344-21410-003-16S), and compared it to an unselected variety, by measuring growth and ion composition of tissue throughout the year. We found the tolerant variety was superior to the unselected and further selection could be accomplished. This will help farmers in areas where drainage water reuse is an option or in areas where there are sodic soils.

It is necessary to define growing regions for seed production of lesquerella. ARS Researchers at Phoenix, Arizona, grew two species of Lesquerella plants at different temperatures in controlled growth chambers at USWCL and measured plant development, the length of time required to reach the next growth stage, and seed and oil characteristics. Growing degree days were estimated using a baseline temperature determined as when growth stops. This information helps explain the relationship between temperature of a potential growing region and seed production.

Improvements in management practices and yields of lesquerella are needed on farmers' fields for progress in commercialization. Newly released germplasm selections were planted by ARS Researchers at Phoenix, Arizona in cooperation with Researchers from the University of Arizona and Texas A&M University as part of Project 5344-21410-003-15R on two farms in Arizona during the 2002 -03 growing season to increase seed for a pilot processing plant at ARS, NCAUR, Peoria IL and develop better farm management practices. Over 18,000 kg of seed was produced for crushing, processing, and various bioproduct formulations by an industrial cooperator (Terresolve Inc). Preliminary data indicate drip irrigation could be used as an alternative cost efficient irrigation practice for lesquerella.

Genetic diversity is needed to continue plant improvements of lesquerella and some species either under-represented or not in our collections are on endangered lists. ARS Researchers at Phoenix, Arizona, and cooperators at Texas Parks and Wildlife Department; San Antonio Botanical Gardens; Mercer Arboretum; Center for Plant Conservation; and Truman State University, Missouri, collected and added to our collection new species and accessions for increase and evaluation along with other accessions from previous collection trips. As a result, these accessions are characterized for entry into the National Plant Germplasm System (NPGS) and available for our breeding program. Traits from these new accessions can be used to improve L. fendleri and its profitability as an alternative crop.

Determining the best time of year to harvest guayule for maximum latex yield is needed for growers and industry to plan harvesting schedules. ARS Researchers at Phoenix, Arizona established a replicated test for monthly harvests of guayule to determine biomass and latex yields. Results indicate that for maximum yields plants should be harvested after cooler days begin in the fall and before warmer temperatures begin in the spring. These results should be useful to growers and industry in scheduling harvests for latex.

Water use curves and fertilizer requirements for guayule are needed to formulate production practices for growers. ARS Researchers at Phoenix, Arizona in cooperation with Researchers at the University of Arizona as part of project 5344-21410-003-13R established a replicated test to evaluate the effects of initial soil fertility levels and irrigation levels on guayule. Initial data indicate that faster guayule growth depends upon the amount of water available more than the initial soil fertility level. These results will aid growers and researchers in developing production systems for this new crop.

Methods to delay processing of guayule shrub following harvest, but yet maintaining latex yield need to be developed, since current methods result in the loss of latex within 24 hours after harvest. ARS Researchers at Phoenix, Arizona in cooperation with Researchers at the University of Arizona as part of project 5344-21410-003-13R established a replicated test to evaluate the effects of 10 different storage treatments on latex yields. Results show that proper storage can maintain latex yields for up to four weeks after harvest. These results should be useful to growers and the guayule industry in maintaining latex yields and scheduling processing of the shrub after harvest.

The effects of transplanting date and plant population on yield of guayule latex need to be determined for newly released germplasm. ARS Researchers at Phoenix, Arizona in cooperation with Researchers at the University of Arizona as part of project 5344-21410-003-13R established a replicated test to evaluate the effects of transplanting date and plant population on latex yield and plant growth. Initial results indicate that transplanting date and plant population are not as important as the germplasm line in determining latex yield and plant growth. These results should be valuable to growers in selecting when to plant, what population to use, and which germplasm line to plant.

Advanced variety yield trials were established for guayule at Marana, Maricopa, Safford, and Yuma, Arizona, and Pecos Texas. Seed has also been furnished to cooperators in Mexico, Australia, South Africa, and China for conducting yield trials and germplasm evaluations in those countries. Results indicate that guayule can be successfully grown at these locations.

Publication(s):

Ploschuk, E.L., Cerdeiras, G., Windauer, L., Dierig, D.A., Ravetta, D.A. Alternatives for the development of different species of Lesquerella in Patagonia (Argentina); potential of L. augustifolia. Indust.Crops and Prod. 2003. v. 18 p.1-6.

Dierig, D.A., Grieve, C.M., Shannon, M.C. Selection for salt tolerance in Lesquerella fendleri (Gray) S. Wats. Indust. Crops and Prod. 2003. v. 17 p.15-22.

Adamsen, F.J., Coffelt, T.A., and Nelson, J.M. Flowering and seed yield of Lesquerella as affected by nitrogen fertilization and seeding rate. Indust. Crops and Prod. 2003. v. 18 p. 125-131.

ACCOMPLISHMENTS

2003

PUBLICATIONS

Abbasi, F., F. J. Adamsen, D. J. Hunsaker, J. Feyen, P. Shouse, and M. Th. van Genuchten. 2003. Effects of flow depth on water flow and solute transport in furrow irrigation: field data analysis. *Irrigation and Drainage Engineering* 129(4):237-246. WCL# 2376.

Abbasi, Fariborz, Jirka Simunek, Th. van Genuchten, Jan Feyen, Floyd J. Adamsen, Douglas J. Hunsaker, Theodor S. Strelkoff, and Peter Shouse. 2003. Overland Water Flow and Solute Transport: Model development and field-data analysis. *Irrigation and Drainage Engineering* 129(2):71-81. WCL# 2371.

Adamsen, F. J. and T. A. Coffelt. Flowering, seed yield, and oil content of nine rape cultivars and one crambe cultivar as affected by planting date. *Communications in Soil Science and Plant Analysis.* (Accepted 04-21-04) WCL# 2268.

Adamsen, F. J., T. A. Coffelt, and J. M. Nelson. 2003. Flowering and seed yield of lesquerella as affected by nitrogen fertilization and seeding rate. *Industrial Crops and Products* 18(2003):125-131. WCL# 2162.

Allen, R. G., A. J. Clemmens, C. M. Burt, K. Solomon, and T. O'Halloran. Prediction accuracy for project-wide evapotranspiration using crop coefficients and reference evapotranspiration. *Irrigation and Drainage Engineering*. (Accepted 08-10-04) WCL# 2387.

Allen, R. G., L. S. Willardson, C. Burt, and A. J. Clemmens. 2003. Water conservation questions and definitions from a hydrologic perspective. p. 159-170. *In* 24th Annual International Irrigation Show, San Diego, CA Nov. 18-20, 2003. WCL# 2385.

Barnes, E. M. and D. J. Hunsaker. 2003. Irrigation water requirements. *In Encyclopedia of agricultural, Food, and Biological Engineering*, Marcel Dekker, Inc., 270 Madison, Ave, NY, pp. 549-551. (Accepted 08-23-01) WCL# 2276.

Barnes, E. M., K. A. Sudduth, J. W. Hummel, S. M. Lesch, D. L. Corwin, C. Yang, C. S. T. Daughtry, and W. C. Bausch. 2003. Remote- and ground-based sensor techniques to map soil properties. *Photogrammetric Engineering and Remote Sensing* 69(6): 619-630. WCL# 2295.

Bautista, E. and A. J. Clemmens. Volume compensation method for routing irrigation canal demand changes. *Irrigation and Drainage Engineering*. (Accepted 04-22-04) WCL# 2386.

Bautista, E., T. S. Strelkoff, and A. J. Clemmens. 2003. Border irrigation management implications of imprecise infiltration parameter estimates. *In* 2nd Int. Conference on Irrig. & Drain, Phoenix, AZ, May 12-15, 2003. WCL# 2364.

Bautista, E., T. S. Strelkoff, and A. J. Clemmens. 2003. General characteristics of solutions to the open-channel flow feedforward control problem. *Irrigation and Drainage Engineering* 129(2):129-137. WCL# 2306.

Brooks, T. J., G. W Wall, D. Johnson, R. L. Garcia, and B. A. Kimball. Canopy gas exchange: an open chamber system for field use. *USDA-ARS Handbook.* (Accepted 6-17-1998) WCL# 2193.

Clemmens, A. J. 2003. Canal Automation. *Encyclopedia of Water Science* p. 53-56. WCL# 2343.

Clemmens, A. J. and S. S. Anderson. 2003. Proceedings of the 2nd International Conference on Irrigation and Drainage. 791 p. Clemmens, A. J Anderson S. S. (ed.). WCL# 2378.

Clemmens, A. J., E. Bautista, B. T. Wahlin, and R. J. Strand. Simulation of automatic canal control systems. *Irrigation and Drainage Engineering*. (Accepted 08-30-04) WCL# 2391.

Clemmens, A. J. and D. L. Bjorneberg. New furrow flume for high sediment loads. *Applied Engineering in Agriuclture*. (Accepted 08-11-04) WCL# 2407.

Clemmens, A. J. and J. A. Replogle. 2003. Irrigation Metering. *Encyclopedia of Water Science* p. 495-497. WCL# 2344.

Clemmens, A. J. and J. Schuurmans. 2004. Simple optimal downstream feedback canal controllers: Theory. *Irrigation and Drainage Engineering* 130(1):26-34. WCL# 2309.

Clemmens, A. J., R. J. Strand, and L. Feuer. 2003. Application of canal automation in central Arizona. p. 455-464. *In* 2nd Int. Conference on Irrig. & Drain, Phoenix, AZ, May 12-15, 2003. WCL# 2361.

Clemmens, A. J., T. S. Strelkoff, and E. Playan. 2003. Field verification of two-dimensional surface irrigation model. *Irrigation and Drainage Engineering* 129(6):402-411. WCL# 2238.

Clemmens, A. J., T. S. Strelkoff, and J. A. Replogle. 2003. Calibration of submerged radial gates. *Journal of Hydraulic Engineering* 129(9):680-687. WCL# 2346.

Clemmens, A. J. and B. T. Wahlin. 2004. Simple optimal downstream feedback canal controllers: ASCE test case results. *Irrigation and Drainage Engineering* 130(1):35-46. WCL# 2308.

Coffelt, T. A., D. T. Ray, F. S. Nakayama, and D. A. Dierig. Genotype and environment effects on guayule (parthenium agentatum) latex and growth. *Industrial Crops and Products*. (Accepted 07-14-04) WCL# 2314.

Colaizzi, P. D., E. M. Barnes, T. R. Clarke, C. Y. Choi, P. M. Waller, J. Haberland, and M. Kostrzewski. 2003. Water stress detection under high frequency irrigation with Water Deficit Index. *American Society of Civil Engineers Journal of Irrigation and Drainage* 129:36-43. WCL# 2289.

Colaizzi, Paul D., Edward M. Barnes, Thomas R. Clarke, C. Y. Choi, and P. N. Waller. Estimating soil moisture under low frequency irrigation using the CWSI. *Journal of Irrigation and Drainage Engineering* 129(1):1-70. (Accepted 7/06/04) WCL# 2401.

Cordy, G., N. L. Duran, H. Bouwer, R. Rice, E. Furlong, S. Zaugg, M. Meyer, L. Barber, and D. Kolpin. 2004. Do pharmaceuticals, pathogens, and other organic wastewater compounds persist when wastewater is used for recharge? *Ground Water Monitoring and Remediation* 24(2):58-69. WCL# 2377.

Cousins, A. B., N. R. Adam, G. W. Wall, B. A. Kimball, P. J. Pinter Jr., M. J. Ottman, S. W. Leavitt, and A. N. Webber. 2002. Photosystem II energy use, non-photochemical quenching and the xanthophyll cycle in *Sorghum bicolor* grown under drought and free-air CO2 enrichment (FACE) conditions. *Plant Cell and Environment.* 25:1551-1559. WCL# 2299.

Cousins, A. B., N. R. Adam, G. W. Wall, B. A. Kimball, P. J. Pinter Jr., M. J. Ottman, S. W. Leavitt, and Webber A.N. 2003. Development of C4 photosynthesis in Sorghum leaves grown under free-air CO2 enrichment (FACE). *Journal of Experimental Botany* 54: 1969-1975. WCL# 2335.

Derner, J. D., H. B. Johnson, B. A. Kimball, P. J. Pinter Jr, H. W. Polley, C. R. Tischler, T. W. Bouttons, R. L. LaMorte, G. W. Wall, N. R. Adam, S. W. Leavitt, M. J. Ottman, A. D. Matthias, and T. J. Brooks. 2003. Above- and below-ground responses of C3-C4 species mixtures to elevated CO2 and soil water availability. *Global Change Biology* 9:452-460. WCL# 2373.

Dierig, D. A. Recent Developments in Stress Tolerance Breeding in Oilseed Crops. *Haworth Press*. (Accepted 1-10-2003) WCL# 2348.

Dierig, D. A., M. A. Foster, T. Isbell, D. T. Ray, and M. E. Miller. Lesquerella potential for commercialization. *Dekker Encyclopedia of Plant and Crop Science.* (Accepted 02-06-02) WCL# 2325.

Dierig, D. A., C. M. Grieve, and M. C. Shannon. 2003. Selection for salt tolerance in lesquerella fendleri (gray) s. wats. *Industrial Crops and Products* 17:15-22. WCL# 2331.

Dierig, David A., Pernell Tomasi, Andrew M. Salywon, and Dennis T. Ray. Improvement in hydroxy fatty acid seed oil content and other traits from interspecific hybrids of three Lesquerella species; *Lesquerella fendleri, L. pallida* and *L. lindheimeri*. *Euphytica.*(Accepted 09-07-04) WCL# 2393.

Fitzgerald, G. J. Spider mite detection in cotton using hyperspectral imagery and spectral mixture analysis. *Precision Agriculture*. (Accepted 3-31-2003) WCL# 2315.

Fitzgerald, G. J. 2004. Portable hyperspectral tunable imaging system (PHYTIS) for precision agriculture. *Agronomy Journal* 96:311-315. (Accepted 7/24/2003) WCL# 2357.

Fitzgerald, G. J., D. J. Hunsaker, E. M. Barnes, T. R. Clarke, S. M. Lesch, R. Roth, and P. J. Pinter Jr. 2003. Estimating cotton crop water use from multispectral aerial imagery. 138-148.*In* Irrigation association exposition and technical conference, San Diego CA, Nov. 18-20, 2003. (Accepted 07-30-03) WCL# 2382.

Grant, Robert F., Bruce A. Kimball, Gerard W. Wall, Jonathan M. Triggs, Talbot J. Brooks, Paul J. Pinter, Matthew M. Conley, Micheal J. Ottman, Robert L. Lamorte, Steve W. Leavitt, Thomas J. Thompson, and Allan D. Matthias. Climate change effects on water requirements of irrigated sorghum: projections from a model tested with a free air co2 enrichment (FACE) experiment. *Agronomy Journal.* (Accepted 06/01/04) WCL# 2394.

Hunsaker, D. J., P. J. Pinter Jr., E. M Barnes, and B. A. Kimball. 2003. Estimating cotton evapotranspiration crop coefficients with a multispectral vegetation index. *Irrigation Science*. Vol. 22(2):95-104. (Accepted 06-18-03) WCL# 2351.

Hunsaker, D. J., P. J. Pinter Jr., G. J. Fitzgerald, T. R. Clarke, B. A. Kimball, and E. M. Barnes. 2003. Tracking spatial and temporal cotton ET patterns with a normalized difference vegetation index. 126-137.*In* Irrigation Association Tech. Conf. in San Diego CA, Nov. 18-20, 2003. (Accepted 07-30-03) WCL# 2381.

Idso, S. B. and C. D. Idso. 2002. Desertification control and greenhouse effect. *Encyclopedia of Soil Science* 331-334. Marcel Dekker, New York, NY. (Published on Internet) WCL# 2257.

Idso, S. B., C. D. Idso, and R. C. Balling Jr. 2002. Seasonal and diurnal variations of near-surface atmospheric CO2 concentration within a residential sector of the urban CO2 dome of Phoenix, Arizona, USA. *Atmospheric Environment* 36: 1655-1660. (Accepted 04/11/01) WCL# 2304.

Idso, S. B. and K. E. Idso. Carbon sequestration in soils to mitigate global warming. *Encyclopedia of Soil Science* Marcel Dekker, New York NY. (Published on Internet) WCL# 2278.

Idso, S. B. and K. E. Idso. 2003. Global temperature change and terrestrial ecology. *Encyclopedia of Water Science* 321-323. Stewart, B. A. and Howell T. A. Marcel Dekker New York NY (ed.) . (Published on Internet) WCL# 2260.

Keys, R. N., D. T. Ray, and D. A. Dierig. Characterization of Apomictic potential in guayule (parathenium argentatum gray) in vivo and in vitro. *Journal of American Society of Horticulture Science*. (Accepted 11/28/2001) WCL# 2228.

Kimball, B. A. Global Change and Water Resources. *American Society of Agronom6y Monograph Series*. (Accepted 9-22-03) WCL# 2324.

Kimball, B. A. Response of plants to elevated atmospheric CO2. *Indian Journal of Plant Physiology*. (Accepted 06-01-03) WCL# 2372.

Kimball, B. A. 2003. Global environmental change implications for irrigation water requirements. p. 87-105. *In* 2nd Int. Conference on Irrig. & Drain, Phoenix, AZ, May 12-15, 2003. (Accepted 11-26-02) WCL# 2358.

Leavitt, S. W., S. B. Idso, B. A. Kimball, J. M. Burns, A. Sinha, and L. Stott. The effect of long-term atmospheric CO2 enrichment on the intrinsic water-use efficiency of sour orange trees. *Chemosphere*. (Accepted 1-3-2001) WCL# 2318.

Moran, M. S. Thermal responses as indicators of plant ecosystem health. J. Luvall and D. Quattrochi (ed.) *In Thermal Remote Sensing in Land Surface Prooperties.* (Accepted 03-02-03) WCL# 2093.

Moran, M. S., G. J. Fitzgerald, A. Rango, C. L. Walthall, E. M. Barnes, W. C. Bausch, T. R. Clarke, C. S. Daughtry, J. H. Everitt, J. L. Hatfield, K. M. Havstad, T. J. Jackson, N. R. Kitchen, W. P. Kustas, M. R. Mcguire, P. J. Pinter Jr., K. A. Sudduth, J. S. Schepers, T. J. Schmugge, P. J. Starks, and D. R. Upchurch. 2003. Sensor development and radiometric correction for agricultural applications. *Photogrammetric Engineering & Remote Sensing* 69:705-718. WCL# 2323.

Moran, M. S., D. C. Hymer, J. Qi, and Y. Kerr. 2002. Monitoring agricultural crop and soil conditions by combining ERS-2 SAR and Landsat TM imagery. *Remote Sensing of Environment*. 79:243-252. (Accepted 07-17-00) WCL# 2152.

Mozingo, R. W., T. A. Coffelt, S. W. Swann, and P. M. Phipps. 2004. Registration of wilson peanut. *Crop Science*. 44:1017-1018. (Accepted 05/01/03) WCL# 2354.

Nunes, V. S. and N. L. Duran. 2003. Bioluminescent genes and their use in environmental studies. *Brazilian Journal of Microbiology* 34:1571-8382. WCL# 2326.

Perea, H., T. S. Strelkoff, J. Simunek, E. Bautista, and A. J. Clemmens. 2003. Unsteady furrow infiltration in the light of the Richard's equation. p. 625-636. *In* 2nd Int. Conference on Irrig. & Drain, Phoenix, AZ, May 12-15, 2003. WCL# 2369.

Pinter Jr., P. J., J. L. Hatfield, J. S. Schepers, E. M. Barnes, M. S. Moran, C. S. Daughtry, and D. R. Upchurch. 2003. Remote sensing for crop management. *Photogrammetric Engineering and Remote Sensing* 69(6): 647-664. WCL# 2352.

Pinter Jr., P. J., J. C. Ritchie, J. L. Hatfield, and G. F. Hart. 2003. The Agricultural Research Service's remote sensing program: An example of interagency collaboration. *Photogrammetric Engineering and Remote Sensing* 69(6): 615-618. (Accepted 1/2003) WCL# 2350.

Ploschuk, E. L., G. Cerdeiras, L. Windauer, D. A. Dierig, and D. A. Ravetta. Alternatives for the development of different species of Lesauerella in Patagonia (Argentina); potential of L. angustifolia. *Industrial Crops and Products*. (Accepted 12-20-2002) WCL# 2347.

Ray, Dennis T., Terry A. Coffelt, and David A. Dierig. Breeding guayule for commercial production. *Industrial Crops and products.* (Accepted 5-07-2004) WCL# 2403.

Replogle, J. A. 2002. Some observations on irrigation flow measurements at the end of the millennium. *Applied Engineering in Agriculture* 18(1):47-55. WCL# 2281.

Replogle, J. A., R. Adler, and R. S. Gooch. 2003. Operational evaluations of new radial gate design. p. 421-433. *In* 2nd Int. Conference on Irrig. & Drain, Phoenix, AZ, May 12-15, 2003. WCL# 2368.

Replogle, J. A. and B. T. Wahlin. 2003. Head loss characteristics of flap gates at the end of drain pipes. *Transactions of the ASAE* 46(4):1077-1084. WCL# 2349.

Robinson, P., A. J. Clemmens, D. K. Carman, Z. Dalmut, and T. Fortner. 2003. Irrigation development in eastern Arkansas: water supplies, uses, and efficiencies. p. 283-292. *In* 2nd Int. Conference on Irrig. & Drain, Phoenix, AZ, May 12-15, 2003. WCL# 2360.

Salywon, Andrew M., David A. Dierig, Jon P. Rebman, and Diana J. Rodriguez. Evaluation of new lesquerella and physaria (Brassicaceae) oilseed germplasm. *American joural of botany*. (Accepted 09-02-04) WCL# 2405.

Soon, W., S. Baliunas, K. Y. Kondratyev, S. B. Idso, and E S. Posmentier. Calculating the climatic impacts of increased CO_2: The issue of model validation. *Special Publication 463 European Space Agency, Noordwijk, The Netherlands.* (Accepted 10/11/2000) WCL# 2243.

Strelkoff, T. S., E. Bautista, and A. J. Clemmens. 2003. Errors inherent in the simplified infiltration parameter estimation. p. 735-745. *In* 2nd Int. Conference on Irrig. & Drain, Phoenix, AZ, May 12-15, 2003. WCL# 2370.

Strelkoff, T. S. and A. J. Clemmens. Transport capacity for eroded silts in irrigation furrows. *Hydraulic Engineering*. (Accepted 07-29-04) WCL# 2389.

Strelkoff, T. S., A. J. Tamimi, and A. J. Clemmens. 2003. Two-dimensional basin flow with irregular bottom configuration. *Irrigation & Drainage Engineering* 129(6):391-401. WCL# 2235.

Tabbara, H. 2003. Phosphorus loss to runoff water 24 hours after application of manure or fertilizer: I. Effects of post-application tillage and rate. *Environmental Quality*. 32:1044-1052. WCL# 2332.

Tamimi, A. H., A. J. Clemmens, E. Bautista, and T. S. Strelkoff. 2003. SIPES - Surface Irrigation Parameter Estimation Software. p. 615-624. *In* 2nd Int. Conference on Irrig. & Drain, Phoenix, AZ, May 12-15, 2003. WCL# 2362.

Triggs, J. M., B. A. Kimball, P. J. Pinter Jr., G. W. Wall, M. M. Conley, T. J. Brooks, R. L. LaMorte, N. R. Adam, M. J. Ottman, A. D. Matthias, S. W. Leavitt, and R. S. Cerveny. Free-air carbon dioxide enrichment (FACE) effects on energy balance and evapotranspiration of sorghum. *Agricultural and Forest Meteorology*. (Accepted 1/13/2004) WCL# 2366.

Wahl, T. L., A. J. Clemmens, and J. A. Replogle. 2003. The energy correction for calibration of submerged radial gates. p. 757-766. *In* 2nd Int. Conference on Irrig. & Drain, Phoenix, AZ, May 12-15, 2003. WCL# 2365.

Wahlin, B. T. Performance of model predictive control on ASCE test canal 1. *Irrigation and Drainage Engineering*. (Accepted 7/14/2003) WCL# 2356.

Wahlin, B. T. and E. Bautista. Feedforward control: volume compensation versus model predictive control. 2003. p. 487-496. *In* 2nd Int. Conference on Irrig. & Drain, Phoenix, AZ, May 12-15, 2003. WCL# 2363.

Wahlin, B. T., A. J. Clemmens, and J. A. Replogle. Procedure for estimating measurement accuracy for surface water flows. *Journal of Irigation and Drainage Engineering*. (Accepted 04/2000) WCL# 2216.

Wall, G. W. and G. McDonnell. 2003. Rapid excision apparatus for plants (reaper): design, implementation, and functionality. *Hortscience* 38(2): 207-211. WCL# 2287.

White, J. W. Solicited book review of Plant Physiology: Characteristics, Breeding and Genetics. *Quarterly Review of Biology* Dris & Barry-Ryan. (Accepted 10/15/2003) WCL# 2383.

White, Jeffrey W. and Consuelo Montes-R. Variation in parameters related to leaf thickness in common bean (phaseolus vulgaris L.). *Field crops research* (Accepted 06-10-04) WCL# 2398.

Zerihun, D., C. A. Sanchez, K. L. Farrell-Poe, F. J. Adamsen, and D. J. Hunsaker. 2003. Performance indices for surface N-fertigation. *Irrigation and Drainage Engineering* 129(3):173-183. WCL# 2311.

Technology Transfer

Following are summaries of the laboratory's major technology transfer accomplishments for 2003.

Irrigation and Water Quality

Scientist: Albert Clemmens **Canal Automation**

Central Arizona Irrigation and Drainage District (CAIDD) purchased the canal automation system developed by the U.S. Water Conservation Laboratory in cooperation with CRADA partner Automata, Inc. The canal automation system was installed in record time and allowed CAIDD to operate their canals remotely within a few months of ordering the system. The district has agreed to implement additional canal automation features provided by Software for Automated Canal MANagement (SacMan) over the next few years. Automata continues to actively market this product with their customers.

Scientist: John Replogle **Flow Measurement and Control**

A canal gate manufacturer, AquaSystems 2000/Inc. was assisted in installing a testing facility for calibrating special accordion-type, vertically-moving gate structures that incorporated the long-throated flume developed at the U.S. Water Conservation Laboratory as an improved measuring and control device for irrigated agriculture. These gates combine the upstream control capabilities of leaf gates, which are similar to lifting the downstream edge of a door across the canal that is hinged at the upstream edge, but without the large lifting force of the leaf gates.

A water-resources products manufacturer, Plasti-Fab, cooperated in laboratory tests to determine head losses caused by their rubberized-hinge flap gates. The tests were conducted at the U.S. Water Conservation Laboratory. These gates are meant to replace standard iron flap gates, which are typically installed on the end of drain lines to prevent backflow and entry of animals. Detailed design information from the laboratory tests is used for the selection and computation of head loss from these special gates. Historical data for the standard iron flap gates, from 8-inch to 48-inch diameter, was gathered from several sources, reformatted in both metric and English units, and combined for both types of gates for ready application by drainage engineers.

New concepts developed at the U.S. Water Conservation Laboratory were presented to the International Conference of the American Society of Agricultural Engineers, for designing and constructing total-load, stream-flow sediment samplers that can also serve as a stream-flow measuring device. Accurate total-load stream flow sampling has been a perpetual problem in sediment monitoring to document erosion into reservoirs and evaluate watershed treatments, which is increasingly important with the recent history of major forest fires. Usually a combination of bed-load sampling devices, suspended-load suction samplers, and a flume for total flow rate, are used. This new concept allows the performance of all three functions with one simplified device.

Environmental and Plant Dynamics

Scientist: Bruce Kimball **Global Climate Change**

Data from the 1998 and 1999 FACE Sorghum experiments on growth, weather, cultural practices, etc. were assembled and converted to a standard ICASA (International Consortium for Agricultural Systems Applications) format. The data were delivered to Dr. Robert Grant, University of Alberta, Edmonton, Alberta for use in validating the ecosys model. The data are now readily available for delivery to other plant growth modelers upon request. Similarly, our data from FACE Wheat experiments conducted between 1993 and 1997 continue to be utilized by plant growth modelers for validation purposes.

Scientist: Terry Coffelt **New Crops**

Seed of six guayule germplasm lines developed jointly with the University of Arizona was shared with a commercial company (Yulex) for establishing commercial fields of guayule in Arizona and California. Seed of these lines is also being shared with research cooperators in Australia, South Africa, and China.

Scientist: Dave Dierig **New Crops**

Seed of newly developed lesquerella germplasm was shared with cooperators in Saltillo, Mexico. Seed will be used in field experiments for a salinity study which is part of a student grant from International Cooperation between the U. S. and Mexico.

ARS WEEKLY ACTIVITY REPORTS

Throughout the year scientists submit items for the "ARS Weekly Activity Report. These reports are consolidated at ARS Area level and submitted to ARS headquarters for the information of agency and departmental management.

ARS Scientist Addresses 2nd International Congress of Plant Physiology in India: On 11 January 2003, Bruce A. Kimball, Research Leader with the U.S. Water Conservation Laboratory, Phoenix, AZ, presented a plenary lecture on "Response of plants to elevated atmospheric CO_2" at the 2nd International Congress of Plant Physiology in New Delhi, India. The Congress was organized by the Indian Society for Plant Physiology, the Indian Agricultural Research Institute, and the International Association for Plant Physiology. Dr. Kimball also chaired a session on "Global climatic change and plant productivity."

STAFF

U. S. WATER CONSERVATION LABORATORY STAFF

PERMANENT EMPLOYEES

Name	Title
Adamsen, Floyd J.	Soil Scientist
Arterberry, Carl K.	Agricultural Science Research Technician Soil
Askins, JoAnne	Physical Science Technician
Bautista, Eduardo	Agricultural Engineer
Bouwer, Herman	Research Hydraulic Engineer (retired 1/03/03)
Clarke, Thomas R.	Physical Scientist
Clemmens, Albert J.	Lab Director, Supvy Res Hydr Engr
Coffelt, Terry A.	Research Geneticist (Plants)
Conley, Matthew M.	Biological Science Technician (Plants)
Dahlquist, Gail H.	Agricultural Science Research Technician (Plants)
Dierig, David A.	Research Geneticist (Plants)
Draper, T. Lou	Secretary (Office Automation)
Duran, Norma	Microbiologist
Evans, Sharette M.	Physical Science Technician
Fitzgerald, Glenn J.	Research Argonomist
Harner, Paulina A.	Secretary (Office Automation)
Hunsaker, Douglas J.	Agricultural Engineer
Johnson, Kathy J.	Physical Science Technician
Johnson, Stephanie M.	Biological Science Technician
Kimball, Bruce A.	Research Leader and Supervisory Soil Scientist
Leake, Greg S.	Biological Science Technician (Plants)
Maneely, Suzette M.	Biological Science Technician (Plants)
Mastin, Harold L.	Computer Assistant
Mills, Terry A.	Computer Specialist
Nakayama, Francis S.	Research Chemist (retired 1/03/03)
Olivieri, Laura M.	Biological Science Technician
Pettit, Dean E.	Electronics Engineer
Pinter, Jr., Paul J.	Research Biologist
Powers, Donald E.	Physical Science Technician
Replogle, John A.	Research Hydraulic Engineer (retired 1/03/03)
Rokey, Ric R.	Biological Science Technician (Plants)
Strand, Robert J.	Engineering Technician
Strelkoff, Fedja	Research Hydraulic Engineer/Research
Stricklin, Deborah K.	Office Automation Clerk
Vinyard, Stephen H.	Physical Science Technician
Wahlin, Brian T.	Civil Engineer
Wall, Gerard W.	Plant Physiologist
White, Jeffery	Plant Physiologist
Williams, Clinton	Soil Scientist

ADMINISTRATIVE OFFICE

Name	Title
Adkisson, Eiko	Administrative Officer
Alexander, Regan	Purchasing Agent
Gerard, Robert J.	Maintenance Worker (retired 1/03/03)
Lee, Richard E.	Custodial Worker
Martin, Kevin R.	Maintenance Mechanic Supervisor
McNeely, Annette	Budge and Accounting Technician
Schoenholz, Jason L.	Maintenance Worker
Sexton, Judith A.	Purchasing Agent (retired 1/03/03)
Steele, Terry L.	Safety & Occupational Health Specialist
Worthen, Michelle	Office Automation Assistant

TEMPORARY EMPLOYEES

Name	Title
Adam, Neal R.	Plant Physiologist
Amann, Michael A.	Engineer Technician
Ashley, Amy F.	Biological Science Technician
Blank, Melissa A.	Biological Science Technician
Bodey, Deanna	Bilogical Science Aid
Boyle, Nanette	Physical Science Aid
Christy, Nathaniel	Biological Science Aid
Cox, Daniel	Biological Science Aid
Dawson, Heather	Biological Science Aid
DeVore, Matthew	Biological Science Aid
Eshelman, Trathferd G.	Physical Science Technician
Faber, Amy	Physical Science Technician
Jackson, Ryan	Billogical Science Aid
Jerman, James A.	Physical Science Aid
Jerman, Jonathan	Biological Science Technician
Jones, Clinton	Biological Science Aid
Knopf, Allen	Biological Science Aid
LaMorte, Robert	IT Specialist
Lainson, John C.	Biological Science Aid
Luckett, William E.	Physical Science Technician
McCain, Selina	Office Automation Clerk
O’Brien, Jessica L.	Physical Science Aid
Richards, Stacy E.	Biological Science Technician
Salywon, Andrew	Molecular Geneticist
Schmidt, Baran V.	Computer Programmer Specialist
Spencer, Loren	Biological Science Technician

Tomasi, Pernell M.	Biological Science Technician
Tuck, Marie A.	Physical Science Aid
Walker, Amos	Biological Science Technician
Walker, Cynthia	Biological Science Technician
Wittenberg, Elisabeth	Biological Science Technician

TEMPORARY STATE EMPLOYEES

Name	Title
O'Brien, Carrie C.	Research Laboratory Assistant (Staff)
Triggs, Jonathan	Biological Science Aid
Vu, Duong H.T.	Engineering Technician
Perea, Hugo	Post Doc

COOPERATORS

UNIVERSITIES

Arizona State University	Tempe, Arizona
Department of Civil and Environmental Engineering	
Department of Geography	
School of Life Sciences	
California Polytechnic State University	San Luis Obispo, California
Delft University of Technology	Delft, The Netherlands
Louisiana State University	Baton Rouge, Louisiana
Michigan State University	East Lansing, Michigan
Mississippi State University	Starkville, Mississippi
Dept of Agricultural & Biological Engineering	
New Mexico State University	Las Cruces, New Mexico
Northern Arizona University	Flagstaff, Arizona
Northwest Agriculture University	Yangling, Shaanxi, China.
Oregon State University	Corvalis, Oregon
Texas A&M University	Lubbock/Pecos, Texas
Agriculture Experiment Station	
Universidad Autonoma Agraraia Antonio Narro (UAAAN)	Saltillo, Mexico
Universidad de Buenos Aires	Buenos Aires, Argentina
University of Akron	Akron, Ohio
Department of Chemistry	
University of Alberta	Edmonton, Canada
University of Arizona	Tucson, Arizona
Campus Agricultural Center	“
Dept of Agri & Biosystems Engineering	“
Dept. of Entomology	“
Dept of Plant Sciences	“
Dept of Soil, Water & Env Science	“
Laboratory of Tree-Ring Research	“
Maricopa Agriculture Center	Maricopa, Arizona
Maricopa Agriculture Center	Phoenix, Arizona
Marana Agricultural Center	Marana, Arizona
Maricopa County Extension Service	Phoenix, Arizona
Safford Agricultural Center	Safford, Arizona
Yuma Agricultural Center	Yuma, Arizona
University of Colorado	Boulder, Colorado
University of Florida	Gainesville, Florida
University of Georgia	
Dept of Biological & Agric Engineering	Athens, Georgia
University of Guelph	Guelph, Ontario, Canada
University of Illinois	Chicago, Illinois
Natural Resources and Environmental Sciences	Urbana, Illinois

University of Mississippi	Stoneville, Mississippi
University of Montana	Missoula, Montana
University of Nebraska	Lincoln, Nebraska
Dept of Biological Systems Engineering	
University of Queensland	Gatton, Queensland, Australia
Virginia State University	Petersburg, Virginia
Virginia Tech Univ-Virginia Agric Exp Station	Suffolk, Virginia
Vrije Universiteit of Amsterdam, University of Amsterdam	Amsterdam, Netherlands

STATE, COUNTY, AND CITY AGENCIES

Arizona Department of Water Resources	Phoenix, Arizona
City of Tolleson	Tolleson, Arizona

FEDERAL LABORATORIES

Brookhaven National Laboratory	Upton, New York
NASA Goddard Institute for Space Studies	New York, New York
NASA, Stennis Space Center	Stennis, Mississippi
National Germplasm Resources Laboratory	Beltsville, Maryland
Natural Resources Conservation Service	
National Water and Climate Center	Portland, Oregon
National Water Management Center	Little Rock, Arkansas
U.S. Department of Energy	Washington, DC
Environmental Sciences Division	
USDI-USGS	Tucson, Arizona
USDA-ARS, Citrus and Subtropical Products Laboratory	Winter Haven, Florida
USDA-ARS, Grassland Protection Research	Temple, Texas
USDA-ARS, National Soil Dynamics Laboratory	Auburn, Alabama
USDA-ARS, Northwest Irrigation and Soils Res Laboratory	Kimberly, Idaho
USDA-ARS, Plant Germplasm Introduction Station	Pullman, Washington
USDA-ARS, George E Brown Salinity Laboratory	Riverside, California
USDA-ARS, South Central Agricultural Research Lab	Lane, Oklahoma
USDA-ARS, Southwest Watershed Research Lab	Tucson, Arizona
USDA-ARS, Western Wheat Quality Laboratory	Pullman, Washington
USDA-ARS, National Center for Agricultural Utilization Res	Peoria, Illinois
USDA-ARS, Western Regional Research Center	Albany, California
USDA-ARS, National Center for Genetic Resources Preservation	Ft. Collins, Colorado
USDA-Forest Products Laboratory	Madison, Wisconsin

OTHER

Agriculture & Agri-Food Canada	Quebec, Canada
Horticultural R&D Centre	

Agricultural Research Council of South Africa	Elsenberg, South Africa
Aqua Systems	Lethbridge, Alberta, Canada
Automata, Inc.	Nevada City, California
Center for the Study of Carbon Dioxide and Global Change	Tempe, Arizona
Central Arizona Irrigation and Drainage District	Maricopa, Arizona
Citrus Research and Education Center	Lake Alfred, Florida
Crops Technology, Inc.	Winston Salem, North Carolina
Imperial Irrigation District	Imperial, California
International FloraTech	Chandler, Arizona
GCTE (Global Change Terrestrial Ecosystems) Wheat Network	Oxon, United Kingdom
IMTA (Mexican Institute for Water Technology)	Cuernavaca, Mexico
Maricopa-Stanfield Irrigation & Drainage District	Stanfield, Arizona
National Institute of Agro-Environmental Sciences	Tsukuba, Japan
Native Seed Search	Patagonia, Arizona
Potsdam Institute for Climate Impact Research	Potsdam, Germany
RSA Environmental	California
Salt River Project	Phoenix, Arizona
Terresolve	East Lake, Ohio
Yulex, Corp.	Philadelphia, Pennsylvania