ANNUAL RESEARCH REPORT
U.S. WATER CONSERVATION LABORATORY

2002

USDA - AGRICULTURAL RESEARCH SERVICE
Phoenix, Arizona

ANNUAL RESEARCH REPORT

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U.S. WATER CONSERVATION LABORATORY
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Director’s Message

2002 was a year of pluses and minuses. We lost two scientists: Herman Bouwer who retired in January 2002 and Ed Barnes who resigned in November, 2002 to join Cotton Incorporated. Herman still comes by most days and we hear from Ed occasionally. Ed we wish you well with your new job in North Carolina. We also added two staff members in December 2002. Clinton Williams joins the lab from the California Department of Water Resources, Sacramento CA. Clinton is a soil scientist and will be working on water quality aspects of irrigating with sewage effluent. Jeff White was hired into the Global Change research team and will be working on modeling plant responses to changing atmospheric carbon dioxide concentration. Jeff comes to us from CYMMT, an international research center in Mexico. Welcome Clinton and Jeff.

We were all saddened by the loss of Bud Lewis who passed away on May 6, 2002. He will be missed.

Six of the eight in-house research projects at the laboratory were approved through ARS=s new peer review process by the Office of Scientific Quality and Review (OSQR) and started functioning in 2002 (some late 2001). The New-crop project was written and reviewed in 2002. Global change will start planning for a new project plan in 2003. Our 2002 annual report provides an update on these projects plans.

During 2002, laboratory staff spent many hours with the Smith Group, the Architectural and Engineering firm that is designing the new research facility for ARS at the Maricopa Agricultural Center. During 2002, they completed the 50% design drawings. The drawings and specifications are to be completed by June of 2003. Since congress has appropriated sufficient funds to build the facility, it should go straight from design into contracting and then to construction. We expect to move in some time in 2006.

The Western Rivers Initiative was developed to fund water management research for the Snake/Columbia, Sacramento/San Joaquin, and Lower Colorado River systems. It was put together by the U.S. Water Conservation Lab., the George E. Brown Salinity Lab., the San Joaquin Valley Agricultural Sciences Center, and the Northwest Irrigation & Soils Research Lab. The joint effort outlines problems faced in common by these river basins and offer research directions to help solve existing water management problems. Details on this initiative can be found later in this report.

The laboratory program looks strong and healthy in the near term. In the long term, we need to focus on developing technology that will help growers and water-resource managers to effectively utilize water for the good of the community. This will require increased cooperation with users and additional resources. Leveraging our current resources and strong research program will be needed to bring this about.

Bert Clemmens
Laboratory Director

Dedication

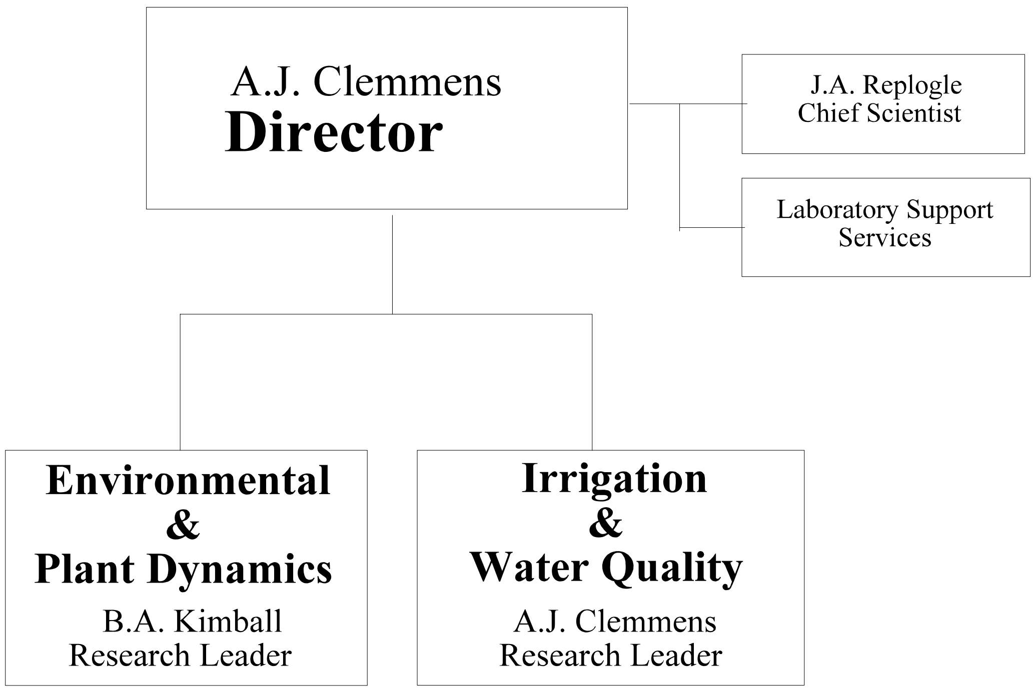
This year there are two employees who have made such an impact on our lab that we dedicate this year's Annual Report to them both.

Herman Bouwer received B.S. and M.S. degrees in land drainage and irrigation from the National Agricultural University of Wageningen, The Netherlands, in 1949 and 1952, respectively, and a Ph.D. degree in hydrology and agricultural water management from Cornell University in 1955. He was then associated with Auburn University's agricultural engineering department in Alabama, where he was responsible for research and graduate teaching in soil and water management. In 1959, he became research hydraulic engineer with the U. S. Water Conservation Laboratory in Phoenix, Arizona, and served as Director from 1972 to1990. His main current projects deal with the role of groundwater recharge in the treatment and storage of sewage effluent for reuse, the effect of groundwater pumping on streamflow, the effect of agriculture on groundwater quality, and regional salinity issues. He is adjunct professor at Arizona State University and the University of Arizona. He has written more than 300 research and technical publications, including one textbook: Groundwater Hydrology (McGraw-Hill, 1978), and 12 book chapters. He has frequently served as consultant to Federal, State, and local agencies in the U.S. and abroad on problems of underground movement of water, renovation and reuse of wastewater, groundwater recharge, and water conservation in general. He received the 1966 Walter L. Huber Research Prize from the American Society of Civil Engineers for early accomplishment and great potential, the 1984 R. J. Tipton Award from the American Society of Civil Engineers for sustained excellence in water management research, the 1985 Area Scientist-of-the-Year Award from the U. S. Department of Agriculture, the 1988 Hancor Award for soil and water engineering from the American Society of Agricultural Engineers, the 1992 Honorary Life Membership Award from the Association of Ground Water Scientists and Engineers of the National Ground Water Association for eminence in the groundwater industry and the many contributions to the field of groundwater recharge, and the 1997 Lifetime Achievement Award from the Arizona Hydrological Society. He has served on two National Academy of Sciences Committees, is a member of the Research Advisory Board of the National Water Research Institute, and serves on the Arizona State Board of Water Quality Appeals. He retired from USDA-ARS in January 2002 but still often comes to work.

Clarence L. Lewis, our favorite "Bud," was the Machinist at the lab from September 20, 1981, until May 6, 2002. Bud was born in Pennsylvania and served in the Army for three years. After serving in the military, be worked as a machinist for Parker White Metal Company in Fairaview, Pennsylvania, before moving to Arizona in 1978 to work for Rotorway Aircraft, Inc., in Chandler. In 1981 we were happy to hire him as a machinist to supervise and manage the shop area. During his career, we were often amazed at his vast knowledge of machining, fabricating, welding, and designing. Examples of his abilities are shown in the many items he designed and fabricated that enhanced the success of our experiments from the 10-foot tall articulated "Bidirectional Reflectance Factor" measurement device (called "The Dinosaur" because it looked like an abstract brontosaurus) to an intricate, finely machined camera mount. His greatest value to the lab, however, was as a teacher. He had infinite patience in sharing the tricks he had learned in his lifetime of fabrication work with the rank amateurs among us who constantly peppered him with questions, often the same questions repeated many times. Bud's life has touched us all. Many remember the love and compassion he had for his first wife Ann until her death and his lovely children Toni and Ty. Then Bud was blessed with another love and eventually second wife, Laurie. Laurie and Bud worked numerous years together at the lab and many of us can tell you stories of the humor they shared. We still laugh about how Laurie bought Bud for $2 and kept the receipt on her refrigerator. Bud and Laurie have been a big inspiration. Bud passed away on May 6, 2002 and, yes, Bud, we were all your family and will miss you dearly!

Laboratory Program

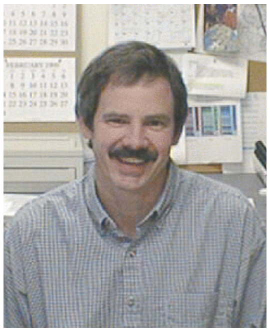
Laboratory Organization



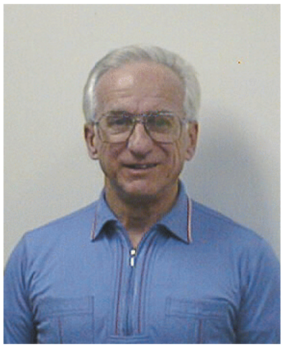
Mission

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 2002:

- Evaluated the Palm Pilot (m105) versus a Toshiba pocket PC (e740) personal data assistant (PDA) for compatibility to be used as a data logger. Researched and found an RS232 compact flash (CF) serial input/output (I/O) card capable of being used with the Toshiba e740.
- Evaluated several C++ software packages to handle the communications I/O via RS232 interface standards.
- Wrote software in C++ to utilize the compact flash I/O RS232 serial card with hardware handshaking capabilities.
- Continued design of the GEN III proble utilizing a surface-mount microcontroller that is flash programmable and interfaceable to a new 24-cm variable water detection transducer.
- Continued design of a 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.
- Completed multiple field tests of the 10 fiber optic sensing GEN II probes with acceptable results.
- Constructed 60 fiber optic sensing GEN II probes which measure flood irrigation water advance and recession dates and times..
- Continued repairs on LPKF circuit board mill machine and updated the hardware.
- Repairs accomplished: handheld guns, spectrophotometer, paper punch equipment, and microscope.

LIBRARY AND PUBLICATIONS

Lisa DeGraw, 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 2300 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 200 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

C.L. Lewis, Machinist, and "Skip" Eshelman, Physical Science Technician

The machine shop, staffed by one machinist, provides facilities to fabricate, assemble, modify, and replace experimental equipment in support of U.S. Water Conservation Laboratory research projects. With the passing of Clarence “Bud” Lewis, the functions were distributed to laboratory personnel with Trathford “Skip” Eshelman monitoring the shop. The following are examples of work orders completed in 2002:

- Manufactured two 8’ manometer boards
- Cutting and reassembling via welding various lengths and configurations of aluminum irrigation pipes
- Cutting and bending sheet metal parts for cooling system on greenhouses at Cotton Lab
- Manufacturing copper pressure sensing tubes for bottom of radial gate at SRP
- Fabrication of wooden surface skimmers for use at SRP in the radial gate project
- Manufacture of a variable depth pressure sensing tube for use in radial gate project with SRP
- Designing and fabrication of the first Furrowometer
- Repair and maintenance of various tools and equipment used in everyday research

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.

"Experiments for the Classroom." The USWCL web site (www.uswcl.ars.ag.gov/events/exper/exper.htm) contains experiments suitable for high school science classes. We responded to several inquiries about our experiments for students from this site.

AgVentures held at Maricopa Agricultural Center (MAC), February 12 & 14. Scientists from USCL participated in the AgVentures held at MAC. Glenn Fitzgerald and Paul Pinter presented remote sensing concepts while Terry Coffelt, Dave Dierig, and Gail Dahlquist presented New Crops research information to groups of middle and high school children at this event.

Workshop to aid Adelaide, Australia, with the Lower Murray Region of South Autralia's irrigation allocation, February 27-28. Bert Clemmens attended a workshop in Adelaide, Australia, to review rehabilitation options for the Lower Murray Region of South Australia. The region utilizer 20% of the South Australia's River Murray irrigation allocation, but is poorly managed. The workshop was organized by the Department of Primary Industries and Resources, South Australia. While in Australia, Bert examined irrigation practices in other regions along the Murray River.

Arizona Science Bowl, March 2. Kathy Johnson, Mike Wiggett, and Gail Dahlquist participated in the Arizona Science Bowl at Glendale Community College.

Visit by Mexican Students, March 12. Thirty students from the seventh-year irrigation class of the Universidad Autonoma Chapingo, Chapingo, Mexico, visited the laboratory. John Replogle hosted them and presented the overall laboratory history and current programs along with a hydraulic laboratory tour featuring recent innovations involving flumes, Venturi meters, pitot tubes, flap-gate studies and the modification of velocity profiles in pipes to improve flow meter performance and accuracy.

Arizona U.S. Agriculture Day, March 13. Glenn Fitzgerald, Tom Clarke, and Dave Dierig attended the Arizona U.S. Agriculture Day in Phoenix, AZ. They distributed literature about the Water Conservation Laboratory and answered questions from the public about water issues in Arizona agriculture.

Directors Reception of Maricopa Agricultural Center (MAC), April 11. Dave Dierig and Terry Coffelt presented New Crops research to the Directors Receptions of Maricopa Agricultural Center (MAC)> The receptions was held to inform politicians, board of reagents, agribusinesses, and academics about the research being done at MAC.

Automata, Inc. Working on software for Canal Automation, April 16-17. Lenny Fueur from Automata, Inc., visited the lab and was given a demonstration of the SacMan software for canal automation by B3ert Clemmens and Bob Strand. The visit lead to a decision to develop software that provides various levels of automatic control.

Scientist from Hebron University visits lab, April 26, May 28 and June 21.. Akrum Tamimi from Hebron University, on sabbatical at the University of AZ, visited Bert Clemmens, Fedja Strelkoff, and Eduardo Bautista to discuss the progress on new software for estimation of surface irrigation parameters.

American Oilseed Chemist in Quebec, Canada special symposium, May 5-8. Dave Dierig presented a paper on Lesquerella breeding and Terry Coffelt presented one on Vernonia to the American Oilseed Chemists in Quebec, Canada. A special symposium was organized on the progress of commercialization of lesquerella and other oilseed crops by their industrial oilseed division.

Scientist visits Saltillo, Mexico, Octover 21-23. Dave Dierig traveled to Saltillo, Mexico, to begin a study on salt tolerance in lesquerella with cooperator Dra. Diana Jasso de Rodriquez.

Visit by Gila River Indian Community farmers, November 8. Dave Dierig met with farmers from the Gila River Indian Community regarding growing lesquerella on their land.

Governor's Advisory Committee. Throughout the year Bert Clemmens attended meetings of the Governor's Advisory Committee on Agricultural Best Management Practices. This committee was set up by Governor Hull to provide guidance on implementing an interim practice for the Third Management Plans for the state's groundwater Active Management Areas.

Graduate student from Brazil. Terry Coffelt is serving on a committee for a graduate student from Brazil at The University of Arizona.

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:

a. Location physical security was enhanced with the installation of a card access system at the main entry points. All visitors must enter the facility via the main entrance, sign-in and receive and display a visitor badge while on the premises. Vehicle gates have been updated with new electric operators and card readers.

b. 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.

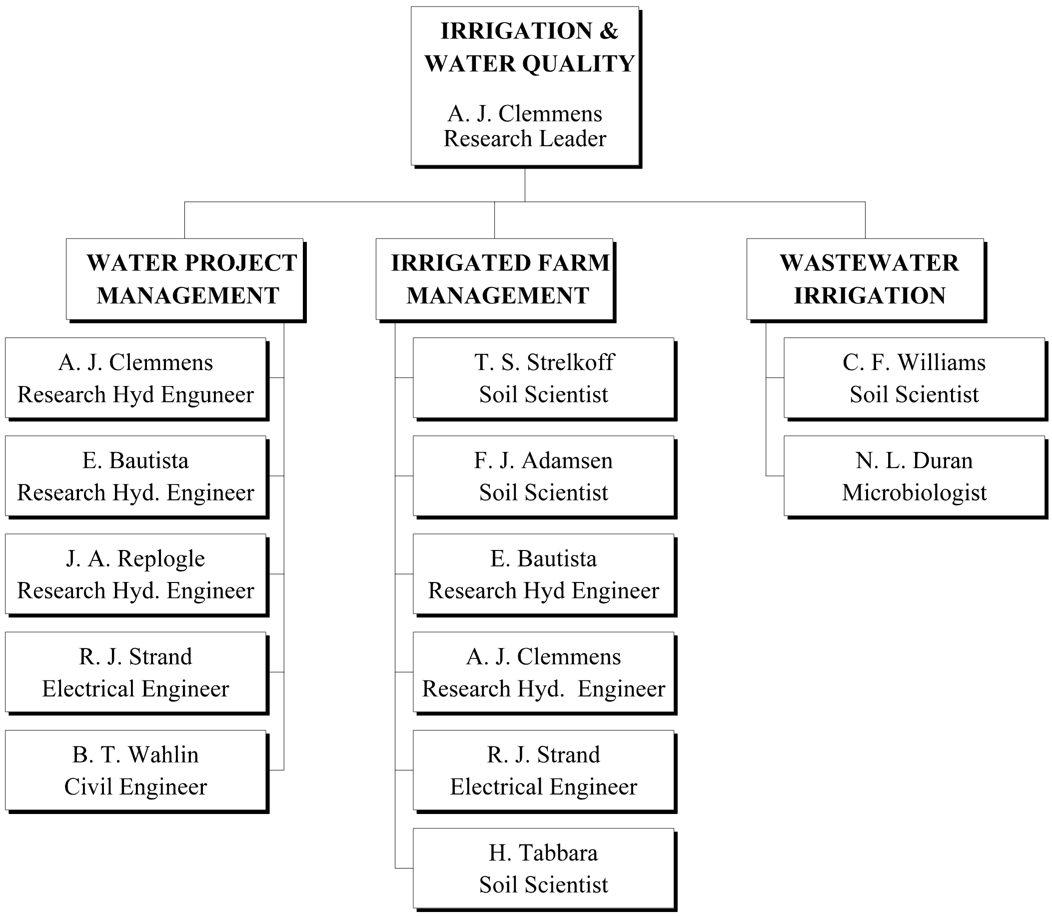
c. Employees are encouraged to report all safety concerns, even those that might seem trivial.

d. 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



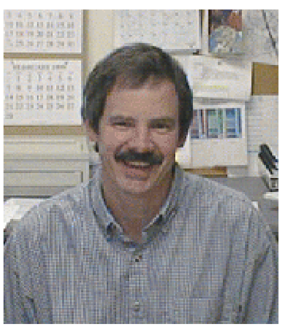
Mission

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

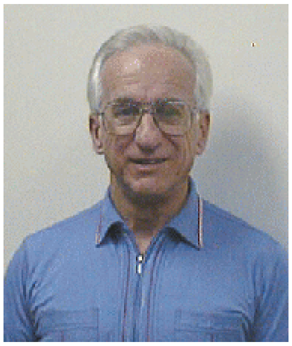
FLOYD J. ADAMSEN, B.S., M.S., Ph.D., Soil Scientist
Management practices that reduce nitrate contamination of groundwater while maintaining crop productivity; application of 100% irrigation efficiency; winter crops for the irrigated Southwest that can be double-cropped with cotton; contributions of natural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



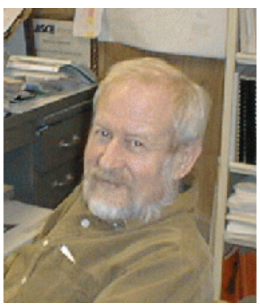
ALBERT J. CLEMMENS, B.S., M.S., Ph.D., P.E., Laboratory Director, Research Leader for Irrigation and Water Quality, and Supervisory Research Hydraulic Engineer
Surface irrigation system modeling, design, evaluation, and operations; flow measurement in irrigation canals; irrigation water delivery system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

ResearchComponent	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

Improving the operation of large water projects is an important step in water conservation efforts to spread limited available water supplies. Engineers from the U.S. Water Conservation Lab, in cooperation with CRADA partner Automata Inc., have developed and canal automation system, which includes Software for Automated Canal MANagement – SacMan. The first version of SacMan was provided to Automata Inc. in 2002, covering manual control with intelligent assistance. This software, including future versions with full automatic control, has significant potential for improving water management in irrigation projects and the CRADA partner has already sold one copy and has interest from several other districts.

Laboratory studies on flow conditioning in pipes and culvert is ongoing. The bugs have been worked out the the measurement methods and the pipe has been set up to handle the variety of tests planned. Several instrument manufacturers have cooperated in various tests and more such cooperation is expected.

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

Initial studies on the control of branching canals were successful. Both Linear Quadratic Regulators and Model Predictive Control were successfully applied to one of the ASCE test canals through computer simulation. The controller design methods were able to account for the interacting influences of the various branches.

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.

Publications:

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Replogle, J.A. Correcting unreliable velocity distributions in short culverts and canal reaches. In USCID/EWRI Conference, San Luis Obispo, CA, July 10-13, 2002.

Wahl, T.L., A.J. Clemmens, M.G. Bos, and J.A. Replogle. Tools for design, calibration, construction and use of long-throated flumes and broad-crested weirs. In USCID/EWRI Conference, San Luis Obispo, CA, July 10-13, 2002.

Wahlin, B.T. and A.J. Clemmens. Preliminary results for downstream feedback control of branching canal networks. In USCID/EWRI Conference, San Luis Obispo, CA, July 10-13, 2002.

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 US 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 wastewater 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 2001 Annual Report

APPROACH AND PROCEDURES: Refer to 2001 Annual Report

PHYSICAL AND HUMAN RESOURCES: Refer to 2001 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:

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.

The project plan for this research was approve by OSQR in April, hence this CRIS project number 5344-32000-002D was created and the previous project CRIS 5344-32000-001D was terminated. Please see CRIS 5344-32000-001D for research accomplishments for soil columns operated under recharge conditions. Field work is in the planning phase in collaboration with the USGS to sample wells in areas in the state of Arizona where ground water recharge with sewage effluent is taking place. Field studies are expected to begin by the first part of FY 2003.

Preliminary laboratory regrowth studies were completed in July and the results have led to further studies involving testing distribution systems at the field, which began in August. Analyses of DNA extracted from samples collected during the annular reactor regrowth study are currently underway to identify specific pathogens using real-time PCR. Future annular reactor studies to determine the physical and chemical parameters that affect regrowth and to test different disinfection methods are currently being planned. Preliminary experiments were performed to test for the biodegradable dissolve organic carbon (BDOC), an important parameter that affects regrowth of bacteria in the reclaimed water. Analysis of the BDOC test results is in progress.

Publications: None

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
17∃-estradiol (ng/L)	<5 - 10	2.7 - 6.3
Estriol (ng/L)	<10 - 37	
Ethyinylestradiol (ng/L)	<0.2	<0.2
Nonyl-phenol (Φg/L)	<0.02 - 330	
2,4-dichlorophenol (Φg/L)	0.061 - 0.16	
Alkylphenols (total)(Φg/L)	27 - 98	
Bisphenol A (Φg/L)	0.02 - 0.05	
Arsenic (Φg/L)	1.3 - 23	
Cadmium (Φg/L)	<0.02 - 150	
Lead (Φg/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 2001 Annual Report

APPROACH AND RESEARCH PROCEDURES: Refer to 2001 Annual Reportg

PHYSICAL AND HUMAN RESOURCES: Refer to 2001 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**	**end of year 5**
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	final reports and manuscript prepared, plan and perform future studies
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	prepare final reports for presentation and publication of papers, plan and perform future studies
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	write papers on best management practices, plan and perform future studies

PROGRESS:

Only scientist on this project retired. Data is being collected on the column studies, where sewage effluent is being used to irrigate grass and alfalfa at various irrigation efficiency or where Colorado River water is being used for recharge. Samples are being analyzed for basic chemical constituents, pathogens, and in cooperation with USGS, various exotic chemicals (e.g., endocryn distupters). A new position has been advertized and should be filed early in FY03.

Publications:

Bouwer, H. Integrated water management for the 21st century: problems and solutions. Irrigation and Drainage Engineering. 128(4), 193-202.

Bouwer, H. 2002. Artificial recharge of groundwater: hydrogeology and engineering. Hydrogeology Journal 10(1):121-142.

Bouwer, H., J. Ludke, and R. C. Rice. 2001. Sealing pond bottoms with muddy water. Journal of Ecol. Eng. 18(2):233-238.

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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
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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 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 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:

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 "safer" 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 fibre-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.

FERTIGATION

Efficient injection of fertilizer into irrigation water fertigation) in surface systems has been hampered by the difficulty of predicting post-irrigation distributions of the chemical. An experimental modification was made to the surface-irrigation simulation program, SRFR, to track the successive fractions of applied inflow -- some with injected chemical in accord with the injection schedule -- assuming no mixing of the fractions. A complementary analysis of farm-scale experiments near Phoenix, AZ, was completed; these utilized tracers to determine the fate of chemicals added to the irrigation water.

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 was made by using a time dependent hydraulic head from a furrow water-depth hydrograph calculated by SRFR as input to HYDRUS to test SRFR's simulation of infiltration. The current focus of the investigation is the application of appropriate boundary conditions to HYDRUS to characterize the influence of variable depth and wetted perimeter in the furrow on infiltration.

MODELING SOIL EROSION AND PHOSPHORUS TRANSPORT

In tracking very small particle sizes, the Laursen transport-capacity formula , the best available for fine sands and silts, yields negative transport capacities. The anomaly was traced to an inconsistency between calculations of the tractive force on particles at the bed surface, which assume fully turbulent flow all the way to the bed, and the critical tractive force at incipient motion, calculation of which recognizes a laminar sublayer in the flow surrounding the small particles. Allowing a laminar sublayer in the tractive force calculations as well eliminated the negative transport capacities.

MEASURING SOIL EROSION AND PHOSPHORUS TRANSPORT

ARS, Kimberly, ID, cooperating with USWCL, conducted field studies on particle-size distributions in the furrow bed and flow, soil- erodibility calibration, and total sediment loads for ultimate model verification. Laboratory tests showed phosphorus 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), and phosphorus concentrations associated with each sediment size were similar. Most of the phosphorus in the furrow tailwater is associated with sediment, but any phosphorus dissolved in the water typically persists, to flow to the river.

PHOSPHORUS DESORPTION IN SURFACE IRRIGATION

To investigate exchanges of soil water and solute with runoff under the relatively quiescent conditions of surface irrigation (no precipitation), a 2.4 m-long instrumented flume 100 mm wide was constructed with a soil bed such that phosphorus desorbed into a non-erosive, initially phosphorus-free inflow could be measured in the runoff. Initial calibration experiments have been performed with local (Avondale) and imported (Portneuf -- Idaho) soil. By placing phosphorus-fertilized soil layers at various depths in the soil bed, the existence of a mixing layer and its dependence on the flow turbulence will be investigated.

GRID-SUPPLIED AND DRAINED LEVEL BASINS

In Southeast Arkansas, in cooperation with the NRCS, an irrigation event was observed on a large level basin constructed with an internal grid of channels for water supply and drainage. Field soil elevations were measured with a GPS unit mounted on a small 4-wheel all-terrain vehicle. The elevations were recorded while driving through the field and along the network of channels. The advancing front was also measured by driving along the front line with the 4-wheeler. The field was seeded to rice, so no data on drainage have been collected.

SURFACE IRRIGATION PARAMETER ESTIMATION SOFTWARE (SIPES)

Construction has begun on a menu-driven Windows program with a number of estimation methods for the field parameters required as input to surface-irrigation simulation and management software. The methods requiring less field data generally make up for the lack by a series of assumptions. The purpose of the software, so-far equipped with 4 estimation methods, is two-fold: 1) to provide action agencies such as NRCS with immediate assistance with their parameter-estimation needs, and 2) to provide a vehicle for studying the tradeoffs between expensive data-gathering efforts and inaccuracies engendered by the assumptions.

SENSITIVITY OF SURFACE-IRRIGATION MANAGEMENT TO FIELD PARAMETERS

A complementary theoretical study was performed for level basins on the effect of variations in infiltration and roughness parameters (relative to the values assumed in design) upon management recommendations. The study showed that when actual advance time is more than assumed, basing inflow cut off on actual advance distance leads to minimal departures from predicted uniformities and efficiencies. But if actual advance time is less than predicted, cutoff based on a given time may be the better approach, independent of variations in infiltration, roughness, and inflow rate.

WATER AND NITROGEN MANAGEMENT OF GUAYULE

A study was initiated on guayule, a latex and rubber plant native to the southwestern U. S. and Mexico and on the verge of commercialization. A site with two very different background fertility levels was selected to determine the daily water use requirements of the crop and the response of guayule to nitrogen management. The crop has been established and the field instrumented with time domain reflectance (TDR) devices and neutron access tubes to follow soil moisture levels. In addition, soil samples have been taken and analyzed to document the fertility of the field sites.

Publications:

Bautista, E., Strelkoff, T. S., Clemmens, A. J. Sensitivity of surface irrigation to infiltration parameters: implications for management. Proceedings 2002 USCID/EWRI Conference -- Energy, Climate, Environment and Water, San Luis Obispo, July 10-13, 2002. p. 475 - 485.

El-Haddad, Z., Clemmens, A. J., El-Ansary, M., Awad, M. Influence of cultural practices on the performance of long level basins in Eygpt. Irrigation and Drainage Systems. 2001. v.15(4). p. 327-353.

Rice, R. C., Hunsaker, D. J., Adamsen, F. J., Clemmens, A. J. Irrigation and nitrate movement evaluation in conventional and alternate-furrow irrigated cotton. Transactions of the ASAE. 2001. v.44(3). p. 555-568.

Strelkoff, T. S., Fernandez-Gomez, R., Mateos, L., Giraldez, J. V., Clemmens, A. J. On tracking sediment particle sizes in furrow-irrigation induced erosion for modeling phosphorus transport. Proceedings 2002 USCID/EWRI Conference -- Energy, Climate, Environment and Water, San Luis Obispo, July 10-13, 2002. p.423 - 433.

THE WESTERN RIVERS INITIATIVE
FOR
SUSTAINABLE AGRICULTURE

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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.

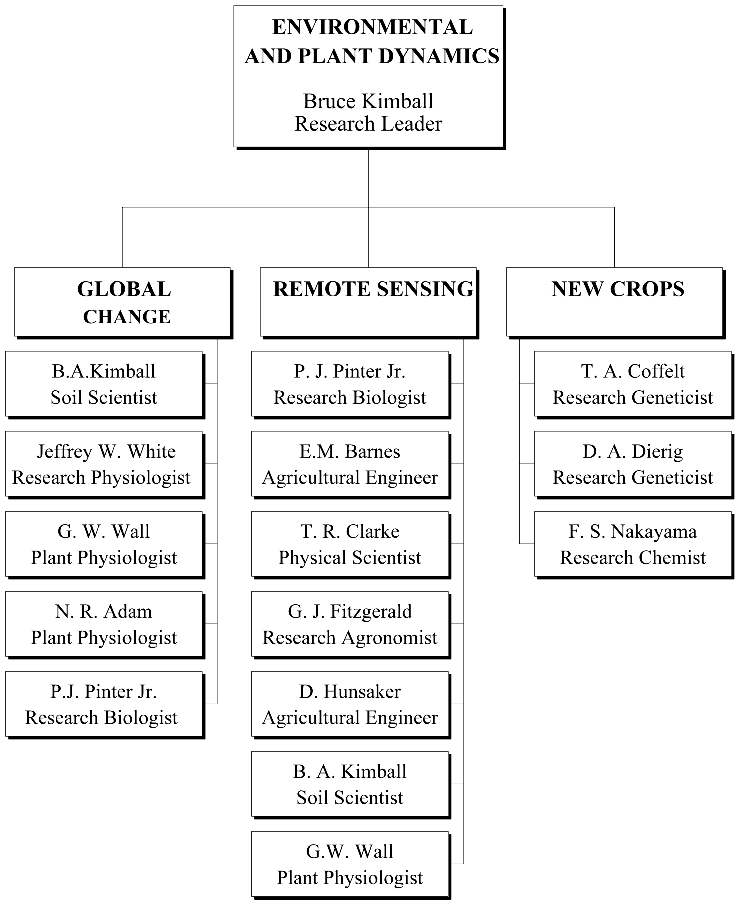
- Managing Water of Impaired Quality: Research studies are needed to determine effective ways to manage saline water supplies and to identify which areas with potential salinity problems are sustainable and which are not. Sustainability includes economic viability. Research is also needed to develop 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.

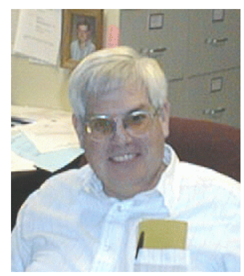
E&PD RESEARCH STAFF

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.

EDWARD M. BARNES, B.S., M.S., Ph.D., Agricultural Engineer
Remote sensing applications for farm management; consideration of approaches that integrate remotely-sensed measurements with crop growth models and decision support systems.

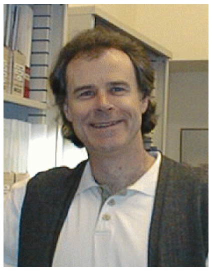
THOMAS R. CLARKE, B.A., Physical Scientist
Remote sensing for farm management, thermal and optical radiometry, and instrument calibration.

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.

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

The continuing rise in atmospheric CO2 concentration is predicted to cause warmer mean air temperatures and altered precipitation patterns, which could increase the likelihood of high temperature extremes and the occurrences of severe drought conditions. To determine the interactive effects of atmospheric CO2 concentration and soil-water content on plants with the C4 photosynthetic pathway, ARS researchers from Phoenix, AZ, in cooperation with scientists from Arizona State University, the University of Arizona, and others, grew grain sorghum under well-watered (Wet) and water-stressed (Dry) soil moisture regimes, and at ambient and 200 ppm above ambient CO2 concentrations using free-air CO2 enrichment (FACE) technology. Compared with control, FACE caused less negative (i.e., improved) total leaf water potentials by 9% and 3% under Dry and Wet, respectively, and it also reduced stomatal conductances by 32% and 37%, while increasing net assimilation rates by 23% and 9%. Therefore, by ameliorating the adverse effects of drought, elevated atmospheric CO2 improved the plant water status for a C4 warm-season annual grass, which indirectly resulted in a net increase in daily and seasonal carbon gain (i.e., growth).

Increasing atmospheric CO_2 concentration and predicted global climate change are likely to affect future water resources in several ways. Therefore, an ARS researcher from Phoenix, AZ, calculated the direct effects of elevated CO_2 on plants, as well as changes due to global warming using a "reference" evapotranspiration (ET) equation, and he reviewed literature stimates of water supply. Slight (2-6%) increases in crop ET were predicted for plausible scenarios of future CO_2 and temperature levels, whereas the predictions for water supply were much more uncertain. Therefore, it behooves future water resource planners and future growers to try to be as flexible as possible.

Rising levels of atmospheric CO2 affect transpiration and water absorption processes that influence total leaf water potential (a measure of a plant's internal water status) of agricultural crops, including wheat – the worlds foremost grain source. To determine the effect of a rise in atmospheric CO2 concentration on total leaf water potential as the soil water content ranged from field capacity to the permanent wilting point, ARS researchers from Phoenix, AZ, grew spring wheat under well-watered (Wet) and water-stressed (Dry) soil moisture regimes, and at 200 ppm above current ambient (about 370 ppm) CO2 concentrations using free-air CO2 enrichment (FACE) technology. Throughout the daylit period, more negative (i.e., improved) total leaf water potential for a given soil water content occurred in FACE-grown plants, which could be traced to both drought-avoidance and drought-tolerance mechanisms. Therefore, as the CO2 concentration of the atmosphere rises, both drought avoidance and tolerance should improve in cool-season annual grasses such as wheat, resulting in an improvement in water relations.

In order to determine the likely overall response of so-called C_4 plants such as sorghum to future high levels of atmospheric CO_2 and possible climate change, it is necessary to establish the interactive effects of elevated CO_2 and drought on photosynthesis. ARS researchers from Phoenix, AZ, in cooperation with researchers from Arizona State University, the University of Arizona, and others, grew sorghum using free-air CO_2 enrichment (FACE) at 550 ppm at ample and limited irrigation, and measurements were made of net leaf photosynthesis and fluorescence. Under drought-stress, FACE increased the quantum yield throughout the day, whereas at ample water, the enhancement occurred only at midday. Therefore, as was also confirmed by other grain yield measurements, future high levels of CO_2 are likely to stimulate sorghum growth under dry conditions but have little effect under well-watered conditions.

Whether or not the storage or sequestration of carbon in soils should be adopted as an international policy to mitigate the rise in atmospheric CO2 concentration is a hotly debated topic, partly because uncertainties exist with regard to how much the elevated CO2 may increase crop growth and stimulate the addition of carbon to the soil and how fast decomposition processes may subsequently return it to the atmosphere. Cooperating researchers from the University of Arizona and ARS researchers from Phoenix, Arizona, exposed wheat to an additional 200 ppm of CO_2 using free-air CO_2-enrichment (FACE) technology, and they found that the FACE treatment stimulated soil respiration rates by 40-70% during peak wheat growth periods. Moreover, carbon isotope analyses indicated some of the increase in respired CO_2 came from old organic matter. Thus, these experiments show that increased losses of soil carbon occur under elevated CO_2, but longer-term full carbon balance studies are needed to resolve the basic question of the net increase in sequestration due to wheat production under elevated CO_2.

In order to determine the likely responses of rangeland and other ecosystems with assemblages of plants to future high levels of atmospheric CO_2 and changing climate, it is necessary to establish the likely competitive advantages among species to these changing factors in their environments. Therefore, ARS researchers from Temple, TX and Phoenix, AZ, in cooperation with others from the University of Arizona and elsewhere, grew sorghum (a so-called C4 plant not expected to respond to CO_2) along with cotton (a so-called C3 plant expected to respond to CO_2) in mixtures and in pure stands under free-air CO_2 enrichment (FACE) at 200 ppm above ambient. In the pure stands, elevated CO_2 increased the growth of cotton but not sorghum, whereas in the mixtures, cotton performance was reduced, indicating sorghum was the superior competitor, yet FACE increased total (sorghum + cotton) biomass production at high plant density. Thus, elevated CO_2 likely will affect future species composition and overall productivity of multi-species ecosystems.

Storage of cryogenically-preserved samples at a cold predetermined temperature is critical in order to maintain the integrity of the specimens. To minimize any risk associated with thawing (sample degradation) during sorting and/or sub-sampling of cryogenically-preserved samples, ARS researchers from Phoenix, AZ, invented a Multi-purpose Cryogenic Surface (MCS) device that is portable, suitable for laboratory or field use, positionally stable, and easily refillable with cryogenic fluid (typically liquid nitrogen). Activity assays and gel separation of photosynthetic enzymes confirmed that the integrity of the sample was maintained though use of the MCS. The MCS has the potential to become the standard operating procedure for sorting and/or subsampling of all cryogenically-preserved samples across a wide range of disciplines.

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IRRIGATED CROP MANAGEMENT UTILIZING REMOTE SENSING

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PROJECT SUMMARY

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

OBJECTIVES

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

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

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

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

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

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

NEED FOR RESEARCH

Description of the Problem to be Solved

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

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

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

Relevance to ARS National Program Action Plan

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

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

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

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

Potential Benefits

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

Anticipated Products

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

Customers

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

SCIENTIFIC BACKGROUND: Refer to 2001 Annual Report

APPROACH AND RESEARCH PROCEDURES: Refer to 2001 Annual Report

PHYSICAL AND HUMAN RESOURCES: Refer to 2001 Annual Report.

Milestones and Expected Outcomes

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

PROGRESS:

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

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

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

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

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

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GERMPLASM IMPROVEMENT
AND
AGRONOMIC DEVELOPMENT
OF
NEW ALTERNATIVE CROPS

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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:

Great potential exists in using waste guayule material for controlling extensive and expensive wood damage caused by insects and microbes. ARS Researchers at the U.S. Water Conservation Laboratory in Phoenix, Arizona, working cooperatively with the U.S. Forest Products Laboratory and the University of Illinois, found that wood made from the waste guayule bagasse and also wood impregnated with guayule resin were shown to be resistant against termite and wood-rot fungal attacks. U.S. and International patent applications have been filed for the fabrication of guayule composite boards with biocontrol properties, and one industry group is interested in licensing the patent when granted. Use of guayule composite boards and/or resin impregnated wood products would reduce the multi-billion dollar damage caused by termites and wood rots each year, as well as reduce the use of pesticides and wood preservatives that are not environmentally friendly.

Knowing when to harvest guayule is critical for maximizing latex yields and quality. A biomonthly harvest test was conducted by ARS researchers at the U.S. Water Conservation Laboratory in Phoenix, Arizona, over a three-year period using an improved approach to the statistical analysis of harvest data. Results indicated that to optimize latex yield harvest should be done between November and April. These results will form the basis of recommendations for industry to use in determining harvesting schedules, thus maximizing yields and crop value.

Industrial users of lesquerella oil need lower costs to improve chances of commercialization of the crop and to successfully grow it in cultivation. Plant breeding by ARS researchers at the U.S. Water Conservation Laboratory in Phoenix, Arizona, has focused on improving yi9elds by mass selecting for higher oil content and seed yield and producing hybrids with higher amounts of hydroxy fatty acids. These advanced generations are significantly improved over the best lines that are now available and a new germplasm line will be release3d as a result. The new lines provide high genetic diversity for future improvements to public and private researchers and an alternative domestic source of hydroxy fatty acids presently filled by imported castor.

Improvements in seed yields of lesquerella are needed on farmers' fields for progress in commercialization. ARS researchers at the U.S. Water Conservation Laboratory in Phoenix, Arizona, in cooperation with researchers from Texas A&M University planted newly released germplasm selections on two farms in Texas and two in Arizona in Fall 2001 to compare the yields from previous grow-outs at these sites. The site with the best yields used a flat field planting methods and obtrained seed yields more than twice that of previous results using older germplasm. The results indicate that lesquerella yields have improved due to better breeding lines and agronomic practices.

Genetic diversity is needed to continue plant improvements of lesquerella. New collections were made from Arizona and Oklahoma by a cooperator from the University of Buenos Aires, and seed wasa increased and evaluated by ARS researchers at the U.S. Water Conservation Laboratory in Phoenix, Arizona, using plant descriptors. Traits related to seed and oil yield were measured. Traits from these new accessions can be used to improve L. Fendleri and its profitabiliyt as an alternative crop.

Lesquerella Breeding and Agronomy: To determine progress in greeding and agronomy of lesquerella, newly released lines were planted on two farms in Texas and two in Arizona in 2001. Farm #1 in Arizona was planted on raised beds with furrow irrigation, and Farm #2 on flat borders with flood irrigation. Germinations at Farm #1 was limited to sides and furrows of beds. A uniform stand was obtained at Farm @2. Seed yields were 1,507 kg/ha at Farm #2., compared to 950 kb/ha at Farm #1. This compares to yields of 714 to 1071 kg/ha in previous tests. Poor stands and lower yields at Farm #1 compared to Farm #2 were presumabely due to salinity on top of the beds. Results indicate that lesquerella yields have improved due to better breeding lines and agronomic practices.

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Technology Transfer

Following are summaries of the laboratory's major technology transfer accomplishments for 2002.

Irrigation and Water Quality

Scientist: Albert Clemmens **Canal Automation**

Software for Automated Canal MANagement (SacMan), developed at the U.S. Water Conservation Laboratory, was turned over to CRADA partner Automata, Inc. during 2002. This software works with commercially available Supervisory Control and Data Acquisition Systems (SCADA) and provides real-time control of canals that distribute water to a large number of users, typical of large irrigation projects. SacMan has a number of features that allow users to gradually phase in automatic controls – starting with manual control and ending with full automatic computer control. The first commercial installation of SacMan also occurred during 2002.

Environmental and Plant Dynamics

Scientists: Paul Pinter, Tom Clarke **Detecting Plant Stress**
Ed Barnes, Glenn Fitzgerald

Provided Chris Humphries of Agrometrics LLC (a commercial provider of remote sensing imagery in both Australia and USA), with practical information for calculating and using the Water Deficit Index and the Canopy Chlorophyll Content Index for determining water and nutrient status of cotton (May 2002).

Scientists: Tom Clarke, Ed Barnes **Agricultural Remote Sensing**

Dr. Matthias Ploechl from the Bornim Institute for Agricultural Engineering (Potsdam, Germany) visited the USWCL from Jan. 26 to March 1, 2002. He learned about interpreting remotely-sensed agricultural observations, the suitability of different wavebands for long term sensing of crop development, and the applicability of remote sensing data to specific crop growth and development models.

Scientists: Terry Coffelt **New Crops**

The Virginia Agricultural Experiment Station, Virginia Polytechnic Institute and State University, and United States Department of Agriculture, Agricultural Research Service, released a new peanut cultivar, 'Wilson', in 2002. Wilson has higher yields than current varieties and early maturity. Excellent pod shape and color characteristics make it ideal for the in-shell market. Foundation seed is being grown by the Virginia Foundation Seed organization and seed should be available to growers as registered and/or certified seed in 2004."

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.

Albert J. Clemmens - A group of farmers and NRCS personnel visit the US Water Conservation Lab: On January 7-9, 2002, a group of farmers and NRCS personnel from the Newlands Irrigation Project in Fallon NV visited the U.S. Water Conservation Laboratory in Phoenix, AZ. Lectures and a field tour provided the group with background and experiences with level-basin irrigation systems and the high productivity and efficiency that can be attained. Of special interest was a novel adaptation of basin irrigation where excess surface water is drained off. NRCS plans to find a demonstration site for this technology in the Fallon area.

Albert J. Clemmens - ARS scientist receives ARS Engineer of the Year Award: On January 18, Bert Clemmens, Laboratory Director for the U.S. Water conservation Laboratory, Phoenix, AZ, will receive the ARS Engineer of the Year Award from the National Society of Professional Engineers (NSPE). The awards ceremony is being held at the National Press Club in Washington, DC. Dr. Clemmens is one of 10 finalists for the Federal Engineer of the Year Award.

Albert J. Clemmens - ARS scientist interviewed: On February 4, 2002, Bruce Kimball, ARS Soil Scientist at the U.S. Water Conservation Laboratory, Phoenix, AZ was interviewed by a reporter from Science/ScienceNOW about a recent paper in Science. The paper by A. Bloom et al. Shows that the response of wheat to elevated concentrations of CO2 is influenced by the form of nitrogen fertilizer available to the plant, with smaller responses obtained with NO3- compared to NH4+.

Albert J. Clemmens - ARS scientists visit the National Water Management Management Center at Little Rock NV: On Feb 13 and 14, Bert Clemmens and Eduardo Bautista, ARS-Phoenix, AZ, and Steve Evett, ARS-Bushland, TX, met with Dennis Carman and Mike Sullivan of the Natural Resources Conservation Service’s National Water Management Center at Little Rock, AR. This Center was established to provide a link between water management technology, particularly ARS technology, and NRCS field offices. The visit served to initiate field studies on irrigation system operations and water management within the Bayou Meto Irrigation Project, east of Little Rock. Dr. Evett just started a 6-month detail there to establish long-term cooperation between the two agencies on technology transfer.

Albert J. Clemmens - US Water Conservation Lab scientist attend workshop in Adelaide, Australia: On Feb 27-28, Bert Clemmens from the U.S. Water conservation Laboratory will be attending a workshop in Adelaide, Australia, to review rehabilitation options for the Lower Murray Region of South Australia. The region utilizes 20% of the South Australia’s River Murray irrigation allocation, but is currently poorly managed. The workshop was organized by the Department of Primary Industries and Resources, South Australia. While in Australia, Dr. Clemmens will examine irrigation practices in other regions along the Murray River.

Bruce A.Kimball - ARS scientist identified as "Highly Cited Researcher." Dr. Bruce A. Kimball, Research Leader at the USDA-ARS U.S. Water Conservation Laboratory, Phoenix, Arizona, has been identified as a "Highly Cited Researcher" in the field of Agricultural Science by the Institute of Scientific Information (ISI, publisher of Current Contents). The "highly cited" designation is an honor bestowed on the world's most cited authors – comprising less than one half of one percent of all publishing researchers. Dr. Kimball's name and résumé are to be posted on 28 March 2002 in the Agricultural Sciences category on ISI's Web site at http://isihighlycited.com.

Glenn J. Fitzgerald - ARS Scientist to Participate in Hyperspectral Remote Sensing Workshop: From March 4-8, Glenn J. Fitzgerald, Research Agronomist, Environmental and Plant Dynamics, US Water Conservation Laboratory, Phoenix, AZ, will present a paper to remote sensing experts from academia, government, and private industry at the Airborne Visible Infrared/Red Imaging Spectrometer (AVIRIS) workshop at Jet Propulsion Laboratory in Pasadena, CA. His presentation, "Detecting Spider Mite Damage in Cotton through Spectral Mixture Analysis of AVIRIS Imagery" will illustrate the practical application and potentials of hyperspectral remote sensing to precision agriculture.

Paul J. Pinter Jr. - ARS Team Collaborates with NASA and DOE: On July 11, remote sensing researchers with the U.S. Water Conservation Laboratory, Phoenix, AZ worked together with scientists from the Commercial Remote Sensing program at NASA's John C. Stennis Space Center in Mississippi and the Emergency Response Team from the Department of Energy's Bechtel Nevada Laboratory. The researchers measured reflected light and surface temperatures of agricultural fields using sensors deployed at ground level and also from helicopter, fixed-wing Cessna, and Lear Jet aircraft. Their joint approach provided an extensive data set that will be used to verify methods for quantifying plant response to environmental stress conditions.

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
Barnes, Edward M.	Agricultural Engineer
Bautista, Eduardo	Agricultural Engineer
Bouwer, Herman	Research Hydraulic Engineer
Clarke, Thomas R.	Physical Scientist
Clemmens, Albert J.	Lab Director, Supvy Res Hydr Engr
Coffelt, Terry A.	Research Geneticist (Plants)
Conley, Matthew M.	Billogical 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)
Lewis, Clarence L.	Machinist
Maneely, Suzette M.	Biological Science Technician (Plants)
Mastin, Harold L.	Computer Assistant
Mills, Terry A.	Computer Specialist
Nakayama, Francis S.	Research Chemist
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
Rish, Shirley A.	Program Analyst
Rokey, Ric R.	Biological Science Technician (Plants)
Strand, Robert J.	Engineering Technician
Strelkoff, Fedja	Research Hydraulic Engineer/Research
Stricklin, Deborah K.	Office Automation Clerk
Tabbara, Hadi	Soil Scientist
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
Gerard, Robert J.	Maintenance Worker
Hodge, Vanessa J.	Budget and Accounting Assistant
Lee, Richard E.	Custodial Worker
Martin, Kevin R.	Maintenance Mechanic Supervisor
Schoenholz, Jason L.	Maintenance Worker
Sexton, Judith A.	Purchasing Agent
Steele, Terry L.	Safety & Occupational Health Specialist
Wiggett, Michael	Administrative Officer
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
Bishop, Lerey R.	Computer Clerk
Blank, Melissa A.	Biological Science Technician
Boyle, Nanette	Physical Science Aid
DeGraw, Christa L.	Office Automation Clerk
DeGraw, Lisa L.	Office Automation Clerk
Eshelman, Trathferd G.	Physical Science Technician
Faber, Amy	Physical Science Technician
Jacob, Sally J.	Biological 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
Lanison, John C.	Biological Science Aid
Luckett, William E.	Physical Science Technician
McCain, Selina	Office Automation Clerk
O’Brien, Jessica L.	Physical Science Aid
Schmidt, Baran V.	Computer Programmer Specialist
Spencer, Loren	Biological Science Technician
Tabbara, Hadi	Soil Scientist

Tanis, David	Biological Science Aid
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)
Richards, Stacy	Biological Science Aid
Triggs, Jonathan	Biological Science Aid
Vu, Duong H.T.	Engineering Technician
Perez, Hugo	

COOPERATORS

UNIVERSITIES

Arizona State University	Tempe, Arizona
Department of Civil and Environmental Engineering	
Department of Geography	
Department of Plant Biology	
Plant Biology	
California Polytechnic State University	San Luis Obispo, California
Kansas State University	Manhattan, Kansas
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.
Peter-Gules van Overloop, van Overloop Consultancy	The Netherlands
Texas A&M University	Lubbock/Pecos, Texas
Agriculture Experiment Station	
Universidad Autonoma Agraraia Antonio Narro (UAAAN)	Saltillo, Mexico
Universita della Tuscia	Viterbo, Italy
Universitat Autonoma	Barcelona, Spain
University of Akron	Akron, Ohio
Department of Chemistry	
University of Alberta	Edmonton, Canada
University of Arizona	Tucson, Arizona
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
Marana Agricultural Center	Marana, Arizona
Maricopa County Extension Service	Phoenix, Arizona
Yuma Agricultural Center	Yuma, Arizona
University of Colorado	Boulder, Colorado
University of Essex	Colchester, United Kingdom
University of Florence	Florence, Italy
University of Florida	Gainesville, Florida
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 Dept of Biological Systems Engineering	Lincoln, Nebraska
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

California Water Quality Control Board	Oakland, California & Sacramento, California
Imperial Irrigation District	Imperial, California
City of Tolleson	Tolleson, Arizona
Maricopa Country Extension Service	Phoenix, 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 Environmental Sciences Division	Washington, DC
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, U.S. 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 Horticultural R&D Centre	Quebec, Canada
Agricultural Research Council of South Africa	Elsenberg, South Africa
Automata, Inc.	Nevada City, California
Center for the Study of Carbon Dioxide and Global Change	Tempe, Arizona
Citrus Research and Education Center	Lake Alfred, Florida
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
Potsdam Institute for Climate Impact Research	Potsdam, Germany
Salt River Project	Phoenix, Arizona
Yulex, Corp.	Philadelphia, Pennsylvania