# NABC Report 24

# *Water Sustainability in Agriculture*


Edited by
Allan Eaglesham, Ken Korth, Ralph W.F. Hardy

2012

# National Agricultural Biotechnology Council Report

**National Agricultural Biotechnology Council**

B15 Boyce Thompson Institute, Ithaca, NY 14853
607-257-4856 Fax-254-8680 NABC@cornell.edu
http://nabc.cals.cornell.edu

*Providing an open forum for exploring issues in agricultural biotechnology*

NABC Report 24

# *Water Sustainability in Agriculture*

Proceedings of the twenty-fourth annual conference of the National Agricultural Biotechnology Council, hosted by the University of Arkansas and the University of Arkansas Division of Agriculture, Fayetteville, June 11–13, 2012

*Edited by*
Allan Eaglesham, Ken Korth and Ralph W.F. Hardy

*Published by the*
National Agricultural Biotechnology Council
Ithaca, New York 14853

NABC Report 24

*Water Sustainability in Agriculture*

The National Agricultural Biotechnology Council provides an open forum for the discussion of issues related to the impact of biotechnology on agriculture. The views presented and positions taken by individual contributors to this report are their own and do not necessarily reflect the opinions or policies of NABC.



*NABC Report 24 is available for $10.00 to cover post and packaging.*
*Please make checks or purchase orders payable to NABC/BTI.*
*It is available for free download at http://nabc.cals.cornell.edu.*

National Agricultural Biotechnology Council
Boyce Thompson Institute B15
Tower Road
Ithaca, NY 14853

607-254-4856  fax-254-8680
nabc@cornell.edu
http://nabc.cals.cornell.edu


Library of Congress Control Number: 2012954078

*Page layout and design by Raymond C. Wiiki (rcwiiki@fairpoint.net)*
*Printed on recycled paper at the Jacobs Press, Auburn, NY (http://www.jacobspress.com/)*

# National Agricultural Biotechnology Council

*Providing an open forum for exploring issues in agricultural biotechnology*

Established in 1988, NABC is a consortium of not-for-profit agricultural research, extension and educational institutions.

Boyce Thompson Institute
Cornell University
Michigan State University
North Carolina State University
North Dakota State University
The Ohio State University
Oklahoma State University
Oregon State University
The Pennsylvania State University
South Dakota State University
Texas A&M University
University of Alberta
University of Arizona
University of Arkansas
University of California at Davis
University of Connecticut
University of Florida
University of Illinois at Urbana-Champaign
University of Kentucky
University of Manitoba
University of Minnesota
University of Missouri-Columbia
University of Nebraska-Lincoln
University of Saskatchewan
US Department of Agriculture/Agricultural Research Service
Washington State University

## NABC Reports Available

### In Hard Copy:

*NABC Report 6—Agricultural Biotechnology and the Public Good* (1994)
*NABC Report 8—Agricultural Biotechnology: Novel Products and New Partnerships* (1996)
*NABC Report 9—Resource Management in Challenged Environments* (1997)
*NABC Report 10—Agricultural Biotechnology and Environmental Quality: Gene Escape and Pest Resistance* (1998)
*NABC Report 13—Genetically Modified Food and the Consumer* (2001)
*NABC Report 14—Integrating Agriculture, Medicine and Food for Future Health* (2002)
*NABC Report 15—Biotechnology: Science and Society at a Crossroad* (2003)
*NABC Report 16—Agricultural Biotechnology: Finding Common International Goals* (2004)
*NABC Report 17—Agricultural Biotechnology: Beyond Food and Energy to Health and the Environment* (2005)
*NABC Report 18—Agricultural Biotechnology: Economic Growth Through New Products, Partnerships and Workforce Development* (2006)
*NABC Report 19—Agricultural Biofuels: Technology, Sustainability and Profitability* (2007)
*NABC Report 20—Reshaping American Agriculture to Meet its Biofuel and Biopolymer Roles* (2008)
*NABC Report 21—Adapting Agriculture to Climate Change* (2009)
*NABC Report 22—Promoting Health by Linking Agriculture, Food, and Nutrition* (2010)
*NABC Report 23—Food Security: The Intersection of Sustainability, Safety and Defense* (2011)

### On CD, or from http://nabc.cals.cornell.edu, all of the above excluding *NABC Report 6*, plus:

*NABC Report 11—World Food Security and Sustainability: The Impact of Biotechnology and Industrial Consolidation* (1999)
*NABC Report 12—The Biobased Economy of the 21st Century: Agriculture Expanding into Health, Energy, Chemicals, and Materials* (2000)

# ACKNOWLEDGMENTS

NABC 24—*Water Sustainability in Agriculture*—was hosted by Ken Korth (professor of plant pathology) and Rick Bennett (professor and head of the Department of Plant Pathology) at the University of Arkansas, Fayetteville. We thank Drs. Korth and Bennett and Cindy Morley (departmental administrative manager) for a highly successful conference.

Thanks are due also to program committee members[1] Marty Matlock, Jennie Popp and Andrew Sharpley—and to David Lobb, Howard Wheater and Larry Purcell—for program design and selection of excellent speakers, to Kim Keeney for accounting support and to Nicholas Lawson for logistical backstopping.

Smooth operation of the conference resulted from the excellent efforts of the following:

*Moderators:* Rick Bennett, Ken Korth, Marty Matlock, Andy Pereira and Jennie Pop.

*Workshop Facilitators, Recorders and Reporters:* Patrick Drohan, Chris Henry, Kim Keeney, Ken Korth, Anna McClung, Cindy Morley, Lacey Nelson, Tom Riley Jr., Samantha Roberson, John Rupe and Ray Vester.

*Student Voice Program Administrator:* Susanne Lipari.

*Student Voice Reporter:* Grace Richardson.

*Audio/Visual Operations:* Lacy Nelson.

And we are grateful to the following organizations for their generous financial support of NABC 24: The CHS Foundation, The Arkansas Water Resources Center, the University of Arkansas Office of Research and Economic Development, the University of Arkansas Division of Agriculture Center for Agricultural and Rural Sustainability, the University of Arkansas Graduate School, the Dale Bumpers College of Agricultural, Food and Life Sciences, Beaver Water District and the USDA Southern Regional Water Program.

* * *

On behalf of NABC, we thank Sonny Ramaswamy (ex of Oregon State University, now director of the USDA's National Institute of Food and Agriculture) and Graham Scoles (University of Saskatchewan) for successive, excellent leadership as NABC's chairs, 2011–2012.

Ralph W.F. Hardy
*President*
*NABC*

Allan Eaglesham
*Executive Director*
*NABC*

October 2012

[1]Drs. Korth and Bennett, RWFH and AE also served on the program committee.

# PREFACE

In 2010, NABC published a white paper, *Agricultural Water Security: Research and Development Prescription for Improving Water Use Efficiency, Availability and Quality*,[1] which contained the following summary:

> *The major and growing challenge for society is water. Water is essential for agriculture. Agriculture withdraws 70–80% of fresh water. The global need by 2050 for increased food/feed production for 3.0 billion additional humans and for increased meat consumption in emerging economies coupled with the biobased industrial product opportunities will greatly expand agriculture's need for water. Climate change also will impact water and agriculture. The effects of crop and animal production on water quality—nutrient and pesticide contamination and soil salinization—need to be reduced to meet increasingly stringent quality standards. Expanded, integrated, focused agronomic, agroecological, engineering and genetic research, development and implementation are essential to improve water-use efficiency, availability and quality….*

Given the societal challenge referred to above, the fundamental importance of water to agriculture and the significant varied effects of agriculture on water globally, a logical choice for the theme of NABC's twenty-fourth annual conference was *Water Sustainability in Agriculture*. NABC 24, hosted by the University of Arkansas and the University of Arkansas Division of Agriculture, was convened at Fayetteville Town Center, June 11–13, 2012.

To foster discussion on these issues, NABC 24 was organized under four topics:

- *Agricultural Adaptations to Water Needs*;
- *Developments in Water Management and Policy*;
- *Changing Role of Agriculture in Environmental and Consumer Issues; and*
- *Preparing for Future Challenges of Water Issues*.

A cross-section of interdisciplinary talks was presented[2] to 83 attendees by excellent speakers—from academia, industry, farming, research centers and federal agencies—and at the conclusion of each session, the presenters convened for panel question-and-answer sessions, to reflect on the issues raised and to take comments and questions from the audience. As is traditional at NABC meetings, attendees had an additional opportunity for discussion during a breakout workshop session.[3]

[1]http://nabc.cals.cornell.edu/pubs/WATERandAGRICULTURE.pdf and as an appendix to this volume.

[2]An overview of the presentations is provided on pages 3–6.

[3]Workshop discussions are summarized on pages 9–15.

A poster session[4]—the first at an NABC conference—was held on the evening of the second day. Participants in the *Student Voice at NABC*[5] program attended the plenary sessions and breakout workshops, and then met as a group to identify current and emerging issues relevant to the conference subject matter.[6]

NABC 24 provided an excellent summary of the status of—and challenges inherent in achieving—water sustainability in agriculture. We have a long way to go; we are only in the foothills of Mount Everest. Examples of approaches being implemented were presented. Needed are more agricultural product through increased yield with less water, a smaller agricultural footprint on water, and an integrated systems approach on national, regional and international scales. We must employ all available tools, including engineering, the physical sciences and the biosciences, while addressing environmental and societal issues.

This volume contains an overview of the conference, a summary of the breakout-workshop discussions, manuscripts provided by the speakers[7], the *Student Voice* report, and abstracts and full papers from the poster session. Transcripts of the panel/Q&A sessions are included, as is NABC white paper, *Agricultural Water Security: Research and Development Prescription for Improving Water Use Efficiency, Availability and Quality*.

NABC's twenty-fifth conference—*Biotechnology and North American Specialty Crops: Linking Research, Regulation and Stakeholders*—will be hosted by Texas A&M University[8] and will convene in College Station June 4–6, 2013. Its objective will be to map the actions/steps to an appropriate regulatory process for specialty crops, so that society may benefit from these important components of our food system.

Allan Eaglesham
*Executive Director*
*NABC*

Ken Korth
*Professor of Plant Pathology*
*Department of Plant Pathology*
*University of Arkansas*
*Fayetteville, Arkansas*

Ralph W.F. Hardy
*President*
*NABC*

The figures herein are printed in grayscale. Information may have been lost from graphics received from the speakers in color. Color versions are available at http://nabc.cals.cornell.edu/pubs/pubs_reports.cfm#nabc24.

---

[4]Abstracts and full representations of posters are provided on pages 237–271.

[5]The *Student Voice at NABC* program provides grants of up to $750 to graduate students at NABC-member institutions (one student per institution) to offset travel and lodging expenses. Also, registration fees are waived for grant winners.

[6]The *Student Voice* report is on pages 231–233. Information on the *Student Voice at NABC 25* will be available at http://nabc.cals.cornell.edu/studentvoice/.

[7]In some cases, edited transcripts replace speaker-written manuscripts.

[8]Further information may be accessed via http://nabc25.tamu.edu.

CONTENTS

# PART I—CONFERENCE OVERVIEW

# *Overview of NABC 24 Water Sustainability in Agriculture*

Kenneth L. Korth
*University of Arkansas*
*Fayetteville, Arkansas*

kkorth@uark.edu

Clean abundant water is both biologically and culturally essential to human life. Agriculture, as the major freshwater-consuming activity on earth, is a key player in managing water resources and in shaping future practices and water policies. As our population grows and greater demands are made for food, feed, fiber and biobased industrial products, it is essential that sustainable practices be employed to adapt to changing water needs and conditions. In 2010, the National Agricultural Biotechnology Council (NABC) issued a white paper detailing water-related agricultural issues along with approaches to address some of the related problems (NABC, 2010; Appendix). The 24th annual meeting of the NABC, *Water Sustainability in Agriculture*—held at the University of Arkansas at Fayetteville, June 11–13, 2012—further explored some of the complex issues facing agriculture and future water needs. Discussions were structured around four focal areas, summarized below, but encompassed multiple subjects directly tied to water sustainability in agriculture.

## Agricultural Adaptations to Water Needs

In the first session, on adaptations of agriculture to changing water needs, Hank Venema (International Institute for Sustainable Development) described a program with the dual purpose of managing water phosphate levels while providing economic benefit. Lake Winnipeg is the collection point for a huge watershed, encompassing vast agricultural lands in Canada and the northern United States. Much of the nutrient flow into the lake occurs through a large marshland that is populated with an invasive species of cattail. By harvesting the plant material, using it as a combustible biofuel and recovering the phosphorus for future use, benefits are seen at several levels. This system provides an excellent model for taking a serious environmental issue and attempting to manage it in an economically beneficial way. It was proposed that similar approaches will be applicable in other situations, and that this could serve as a model for a "watershed of the future." This talk served as an excellent starter to the conference, and introduced a theme that came up several times during the three-day meeting. Specifically, that the likelihood of adoption and success of sustainable water management practices will be greater when tied to a clear economic benefit.

Adopting plant genetics and cultural practices were also addressed in the first session. Improving plant drought resistance and water-use efficiency through conventional breeding techniques and via transgenic technologies were highlights of talks from both industry and academic researchers. The recent introduction of commercial crop varieties with enhanced drought performance illustrates the opportunity to minimize the negative impact of moisture deficiency on crop production through genetic modification.

As an alternative to conventional production of annual crops, scientists at The Land Institute are developing perennial crops. Obviously, large-scale adoption of a perennial grain system would require substantial changes in the way US agriculture functions. Although this is a long-term approach and major hurdles remain, the potential environmental and sustainability benefits are attractive. This presented an intriguing set of possibilities and provided the conference with an alternative to many of the conventional means of attacking the problems of water sustainability.

The keynote address, by Marc Andreini (Robert B. Daugherty Water for Food Institute, University of Nebraska), provided a powerful view of water usage in North America as contrasted with water use for drinking and agricultural needs in Africa. Based on his experiences working in Africa over many years, Dr. Andreini summarized the challenges faced by consumers in each system, and emphasized that collaborative approaches and consideration of the needs of end-users are crucial to developing sustainable water practices.

## Developments in Water Management and Policy

The second session focused on water-management policies, and speakers discussed systems at local and national levels. A common theme for this session was the importance of managing point sources of water contamination, especially nitrogen and phosphorus, from agricultural, urban, and industrial runoff. For example, in the United States, the USDA-NIFA Conservation Effects Assessment Project (CEAP) is aimed at assessing the success of conservation practices implemented over a long time frame. At a state level, different models of water-quality trading policies and their relative successes in Ohio were described, with special emphasis on the Alpine Cheese Phosphorus Nutrient Trading Program, which is one of the few programs to have fully met the requirements of its National Pollutant Discharge Elimination System (NPDES) permit. Finally, the importance of identifying farm-based sources of nutrient runoff was highlighted, along with discussion of methods to control runoff. With all of the management practices that were discussed, it was clear that balancing the needs of producers and end-users with the environmental outcomes is essential. Likewise, the specifics of practices that are implemented, *e.g.*, the absolute allowable levels of nutrients in a waterway, might need to be varied depending on the individual watershed that is impacted. Finally, meeting participants were treated to the perspectives of Ray Vester, a fourth-generation rice farmer and a leader among US rice producers. His personal accounts of the changing needs and practices of farmers over a long period in Arkansas provided valuable insight into the frontline problems faced by producers. In many parts of Arkansas, as in areas worldwide that have relied on groundwater-based irrigation, the depletion of aquifers is a primary concern. Coupled with enhanced regulatory and environmental concerns, farmers face many challenges concerning water usage.

## Changing Role of Agriculture in Environmental and Consumer Issues

Session three focused on the role of agriculture and sustainability efforts in environmental and consumer issues. The discussions included academic, government agency, and industry perspectives. The Natural Resources Conservation Service (NRCS) focuses on issues of water use and soil quality, working directly with growers to improve sustainable practices such as decreasing water loss and soil erosion. Michael Sullivan of the NRCS described agency practices, and discussed the many benefits seen by growers who invest in these new approaches. Likewise, participants heard industry perspectives from speakers from Tyson Foods and the Sustainability Consortium, which includes academic, industry, and non-governmental organization members. Based on these talks, it is clear that major companies worldwide are working toward improving sustainable water usage. Industry and farmers alike will be drawn to many of the sustainable practices discussed, not only because it might be the environmentally responsible thing to do, but also because it most often makes good business sense.

## Preparing for Future Challenges of Water Issues

The final session was centered on challenges to be faced by the agricultural sector concerning water use. As with other sessions, the economic benefits of adopting new practices, including use of transgenic crops, were discussed. Likewise, the value in having agricultural producers take a lead role in developing new policies was highlighted; in this way, growers can contribute to assessment of current practices and help shape new strategies. Reagan Waskom (Colorado State University) gave an excellent overview of many of the water-related challenges facing farmers, but also the interrelated impacts that these have on the environment and urban consumers. The overarching challenges were discussed, along with specific case studies and potential approaches to reduce consumption at multiple levels.

## Summary

Based on the speaker presentations, breakout-session discussions and the poster session, it is clear that meeting participants saw that solutions to water-sustainability issues in agriculture will require cross-disciplinary approaches. This is a long-term challenge that will require continuity in terms of research methods and resource availability. Identifying the benefits of sustainable-practice adoption, whether they are economic, environmental or health-related, must play a role in educating end-users and in shaping water-use policies. In terms of biotechnology, an opinion that emerged, held by some at the meeting, was that the research community should show some caution about "over-promising" solutions based solely on improved crops. The water-related problems faced by growers and consumers are massive, and a single technological fix is not likely to solve these large-scale issues.

Water sustainability in agriculture is a complex issue, but it must be addressed because of the importance to worldwide food availability, economic development, human and environmental health, and political security. A recent review highlighting the need for integrative approaches to solving problems of this scale includes discussion of need for new evidence-based models that go beyond a food and farm focus in relief and rebuilding efforts. Attention must be given to broader livelihoods that manage risk while offering new entry points into activities that link vulnerable households to market opportunities (Dubé *et al.*, 2012). Furthermore, a report from the President's Council of Advisors on Science and Technology has identified seven high-priority challenges faced by agriculture, which include increasing the efficiency of water use (PCAST, 2012). This report recommends increasing federal government investment in agricultural research, with the creation of a network of public-private multidisciplinary innovation institutes. Clearly, solutions to water-related challenges will need to be addressed at levels ranging from small farms to regional, national, and multinational agencies.

## References


Dubé L *et al.* (2012) Paths of convergence for agriculture, health and wealth. Proceedings of the National Academy of Sciences of the United States of America 109 12294–12301.

NABC (2010) Agricultural Water Security: Research and Development Prescription for Improving Water Use Efficiency, Availability and Quality. Ithaca, NY: National Agricultural Biotechnology Council. http://nabc.cals.cornell.edu/pubs/WATERandAGRICULTURE.pdf.

PCAST (2012) Report to the President on Agricultural Preparedness and the Agricultural Research Enterprise. Washington, DC: President's Council of Advisors on Science and Technology. http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_agriculture_20121207.pdf.

## PART II — BREAKOUT SESSIONS

# *Workshop Summary*[1]

PATRICK DROHAN
*The Pennsylvania State University*
*University Park, Pennsylvania*

KEN KORTH
*University of Arkansas*
*Fayetteville, Arkansas*

ANNA MCCLUNG
*USDA-ARS*
*Stuttgart, Arkansas*

JOHN RUPE
*University of Arkansas*
*Fayetteville, Arkansas*

RAY VESTER
*E&M Farms*
*Stuttgart, Arkansas*

Four parallel workshops were convened at the end of the second afternoon. Each group addressed the same questions. Reports on the discussions elicited by the questions were delivered orally at the end of the conference by those listed above.

***At this conference, we are discussing both technical and cultural approaches to dealing with challenges of water sustainability. Beyond the specific topics being covered in this meeting,***
***—What technical approaches should be pursued to improve efficiency of water use in agriculture?***
***—What policy changes or educational efforts that should be pursued to help improve cultural practices?***

NEW TECHNOLOGIES:

- Small scale on-farm approaches: drip irrigation; re-use of wastewater for irrigation; run-off capture to control loss of nutrients and soil.
- Identify knowledge gaps for using these new technologies and scientifically document how effective they are, including economic analyses.

[1]The discussions were facilitated by Chris Henry, Anna McClung, Tom Riley Jr. and John Rupe, and notes were taken by Kim Keeney, Cindy Morley, Lacey Nelson and Samantha Roberson.

- Novel technologies need to be approved by NRCS[2] to be eligible for crop insurance and bank-financing of farm operations.
- Identify C4 plants that are better suited for drought-stressed production areas. Consider the potential for conversion of C3 crops to C4 pathways.
- A nationwide systems analysis is needed across agriculture to assess where the most water-efficient crops are being grown in each region. If that analysis concludes that certain crops are performing inefficiently, what infrastructure needs to be developed, and what social shifts need to occur for improvement?
- Additional assessments of water storage are needed, with possible adoption locally of more efficient approaches.
- Replacement of flooded rice with upland rice should be considered.
- Irrigation should be triggered on the basis of soil-moisture content or evapotranspiration measurement.

### Policy/educational changes:

- The Farm Bill should include language that is supportive of innovative water-saving methods and use of water-efficient crops by growers in areas of moisture deficiency.
- Better assessments of land use and regional planning are needed. Irrigation of crops or dairy operations in water-scarce areas (like New Mexico and Arizona) may not be good use of public natural resources. There is need for broader understanding that water is not "free"; societal and environmental impacts result from inefficient use of water.
- Incentives are needed to encourage adoption of new technologies. NRCS is limited on resource availability per project; many more requests are received for support than they can fulfill.
- Education of policymakers and regulators is needed. Large companies are setting priorities, not necessarily for the public good. Fundamental to this is conducting solid science to provide the basis for guiding policy.
- Other countries are more progressive in desalinization programs. We should learn from them, to utilize ocean-water resources for agricultural production.
- Educational opportunities should be provided to farmers to assist them in utilizing remote-sensing technology.
- An analysis is needed encompassing all users of water nationally with the focus on withdrawal reporting.
- In areas where agriculture is not already diversified, diversification should be encouraged in order to secure local needs.

---

[2]National Resources Conservation Service.

- Charging for water usage should be examined, including investigation of how producers would be affected.

***The US Department of State recently launched the US Water Partnership to deal with water challenges that can potentially increase regional tensions and political instability worldwide. How can agricultural researchers best direct their efforts to deal specifically with such social and political aspects of water use?***

- Coordination of research projects across regions could have broad/national impact. For example, research along the Mississippi River should be consolidated, from on-farm point-source pollution and water use to hypoxia in the Gulf.
- Grass-roots interactions will build communities that care about these issues and come together to help solve problems from multi-faceted perspectives.
- The impact of other industries on water use and pollution needs to be documented to achieve better understanding at the watershed level. Agriculture may be receiving greater blame for pollution than is warranted.
- The public needs to better understand the value of products of agriculture (food, fiber, fuel) in relation to its use of natural resources. Public perception of farmers should be as good stewards of natural resources who feed the world.
- The United States should be a leader in good stewardship practices and communicate accordingly with other countries.
- Research on water sustainability should be focused at the producer level. Benefits must accrue to farmers first in order to not only sustain farming, but to ensure adoption of new conservation practices.
- Development of agriculture-related infrastructure should be emphasized within other countries, including germplasm collections, gene banks and marker-selection capability.
- Altruism should be part of student training to encourage the desire to make things better.
- Scientists should take care to show respect for the public at large and the cultural forces that shape public opinion, to avoid giving the impression that they know all there is to know and have all the answers.

***In a recent study, Hoekstra and Mekonnen (2012)[3] estimate that agriculture contributes 92% to the global freshwater footprint of human activity.***
***—Should we be concerned that there is such a high proportion for agricultural use, or are such high amounts inevitable?***
***—Given this high amount, should there be more focus on educating consumers about the needs of agriculture for food production?***

[3]http://www.pnas.org/content/109/9/3232.

Inevitability of high water use:

- The discussion should be reframed to clarify the difference between agricultural water use and water consumption.
- It is essential to be able to estimate accurately agriculture's water footprint. There was consensus that 92% is an over-estimate; recycling of irrigation water was probably not considered.
- Deriving lifecycle models of water use are fraught with difficulties because, inevitably, they become so complex as to be meaningless.

Consumer education:

- There is need to communicate that farmers are not irresponsible about resource use.
- Education is needed at the K–12 level to engender better public understanding of food production, environmental stewardship, and water use for crop and animal production.
- Marketing by industry is more effective at leading the public than is our education system. There is pressing need to reverse the trend of the public being further and further removed from food production and ever more suspicious of science.
- Few consumers understand that many sources of our food are of high water content, requiring significant uptake of water.
- There is need for education, not only in places where water is scarce but nationwide. It can be especially important in areas where water is plentiful. For example, a person in New England may routinely keep a tap running until the water becomes cold for drinking, whereas in the west that's less likely.
- One of the problems with improving awareness of water sustainability is that consumers don't have a metric for comparing products. They have metrics for how many calories are in a product and whether it's organic. Certification or package labeling that an item was produced in a sustainable way would be helpful in promoting awareness and to help consumers make wise choices.

***What other topics are worthy of discussion?***

- We need to more effectively communicate the overall potential impact of agriculture, not only for food and feed production but also on resource use—including water—climate change and human nutrition and health, and use this to justify increased funding because agricultural research has huge potential for addressing 21st-century problems.
- Better understanding is needed of the long-term implications of government policies, such as the Farm Bill, and efforts to improve conservation.
- Better understanding is needed of competition for water resources for agricultural and urban uses. We need to stop blaming farmers and change people's perception

of how this can be a win-win proposition in terms of environmental and ecological economics as well as food and feed production.

- One of the biggest problems is funding; where do we look for it and how do we convince those who have the funds to increase commitments to agricultural research?
- "We are regulating ourselves into the ground."
- More farmer feedback would be helpful.
- Groundwater depletion is an increasingly important issue in Arkansas and elsewhere; it deserved fuller discussion at this conference.
- Grower reluctance to change practices is a significant issue. As an example, in west Texas, at some point growers will be unable to produce cotton due to water depletion, but there is little impetus to adopt conservation practices. Legislation to regulate water use was struck down by the Texas Supreme Court.
- The role of wildlife habitats in water use deserves attention. In Arkansas, for example, some farmers generate as much income from renting flooded fields to duck hunters in the winter as they do from crop production. The farmers may make potentially detrimental adjustments in how they grow their crops to accommodate hunters.
- Given that water is a scale-dependent issue, a focus for a future conference would be to examine areas where water use is intensive, *e.g.* for rice production, for opportunities for crop diversification to decrease water consumption. This would probably be achieved via regional life-cycle analyses.
- Another subject for a future conference is the issue of transferring farms across generations. Young people who wish to enter farming are faced with significant challenges. It is virtually impossible get into agriculture because of land prices, thus threatening future production.
- Another possible conference focus would be to explore what people eat and why. Understanding consumer preferences may help inform farmers to increase their profitability. This could include consideration of the role of technology and the extent to which consumers care about genetically engineered foods.

***Ken Korth: Any comments from the audience?***

Thomas Redick (Global Environmental Ethics Council, Clayton): One of the problems I see is lack of agreement on how much water is used by agriculture. We were given a number by Hoekstra and Mekonnen: 92%. CAST, the Council for Agricultural Science and Technology, produced a report in 2009[4] that 59% is used by agriculture. However, neither of these sources provides a clear idea of how much credit may be allotted to aquifer recharging or how that will be worked out.

---

[4]http://www.cast-science.org/publications/?water_people_and_the_future_water_availability_for_agriculture_in_the_united_states&show=product&productID=2950.

Reagan Waskom (Colorado State University, Fort Collins): It was mentioned that we need better numbers. USGS[5] is doing a national water census right now. It's a 10-year effort. But the problem referred to results partly from the way that we report these numbers. USGS does withdrawals. Other people do consumptive use. Other people now are doing footprinting. We mix and match these and ag doesn't like the way the numbers look. But I want to challenge this, particularly around water footprinting. Tony Allan at King's College, London, came up with the idea of virtual water—how water is embedded in products and processes. He did it not to lay a value on that, but to show how water is moved through various products and around global trade systems, so you can begin to look at substitutions, *etc*. This idea then gets overlain with water footprinting. When you determine a carbon footprint you are looking at a resource that has impacts on climate far beyond its time. If you are looking at water, it is very different. Who cares if it takes half a million gallons to grow 150 bushels of corn in eastern Iowa? If a value is laid on top of that, a consumer may think that's a bad thing: 500,000 gallons to grow 150 bushels. Part of the problem is the way that a value gets overlain on that. Does it matter that half a million gallons are withdrawn from the Ogallala Aquifer to grow that 150? Maybe that's a different discussion. Part of the educational opportunity that we have is to deal with this issue of water footprinting and get away from the idea that it's bad that it takes a lot of water to grow our food. That's the reality of growing beef or corn or whatever. Can we make substitutions? Yes, and that was Tony Allan's point with virtual water. Maybe it doesn't make sense to produce milk in Saudi Arabia—using desalinated water to grow alfalfa to support a dairy industry in the desert. Maybe you just move milk solids from Europe.

David Zilberman (University of California, Berkeley): One system of accounting is the market system and the good thing about the market system is that most of us are paid in dollars. We are not paid by footprints. So, to some extent, even if people hate it, they take it seriously. Now the challenge is to introduce environmental values into a market system. For example, if you have a lot of water in some parts of Canada and you use it for irrigation without environmental implications, then there is no problem. If you draw water from an aquifer it may affect your ability to produce in the future, and that will be something that will enter the economic system. I like virtual water because it is, basically—excuse the expression—economics for dummies. It brings some rational cost of tradeoff into the decision-making. The reality is that we live in a system where we have tradeoffs and we pay for things. The big problem is that a lot of environmental amenities are not translated into things that people are paid for. As long as people don't pay for things we can speak about them as much as we want, but nothing will change. The only thing that may happen is that we will make political decisions that, sometimes, will actually make things worse rather than better. Depleting groundwater, in many cases, is a big problem. Linking all of what we do to some sort of a market economy is important.

[5]United States Geological Survey.

Another thing that is important is to recognize to what extent it may be worthwhile to move water from A to B recognizing that moving water is problematic. It's costly, but there is a lot of benefit.

Becky Cross (USDA National Agricultural Statistics Service, Little Rock): A farmer-based survey is available, the Farm and Ranch Irrigation Survey.[6] I invite everyone to see what data are available and to provide feedback so that the information may be provided in a different, or better, way. That is what we are here for—to tell the story of farming in America.

[6]http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Farm_and_Ranch_Irrigation_Survey/index.php.

## PART III—PLENARY SESSIONS

## AGRICULTURAL ADAPTATIONS TO WATER NEEDS

# *The Lake Winnipeg Bioeconomy Project*

Hank Venema
*International Institute for Sustainable Development*
*Winnipeg, Manitoba*

hvenema@iisd.ca

I will describe an interesting example of how we can use agricultural biotechnology to address a major regional environmental systems problem. The Lake Winnipeg Bioeconomy Project is founded on the idea that a lake—in this case, Lake Winnipeg—can serve as the focus for a transformed agenda around innovative agricultural water management, with the potential to yield economic benefits.

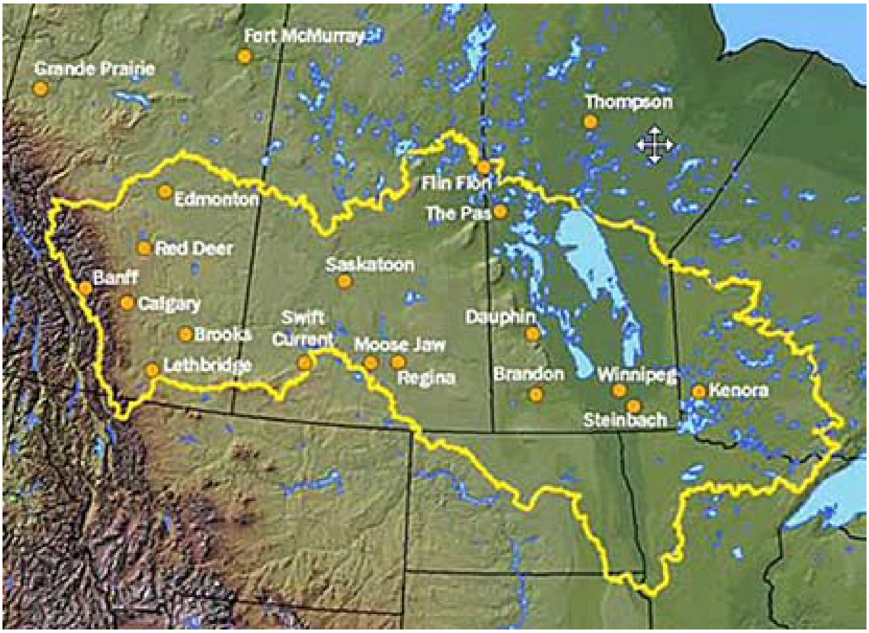



Figure 1. Lake Winnipeg's watershed.

The Project is located at the northern edge of arable land in the upper Great Plains. The watershed draining into Lake Winnipeg straddles the major agricultural provinces of Canada—Manitoba, Saskatchewan and Alberta—and it dips into Montana and South Dakota, and includes large parts of Minnesota and North Dakota (Figure 1). Lake Winnipeg has the interesting property of having the largest watershed area to surface area in the world. It is the 10th largest lake in the world, with an enormous catchment area that includes a huge expanse of agricultural land. Figure 2 provides a view from space, revealing discoloration due to bluegreen algal blooms. It's the freshwater analog of hypoxia in the Gulf of Mexico, which is caused by the farmer-applied nutrient flow into the Mississippi Basin.

Figure 2. Lake Winnipeg showing algal blooms.

## A Problem of Impossible Proportions

On face, amelioration of Lake Winnipeg is a problem of impossible proportions. On the other hand, the words of Secretary of Health, Education and Welfare John Gardner, in 1965, come to mind:

> *What we have before us are some breathtaking opportunities disguised as insoluble problems.*

The key message is that, with the promise of innovative agricultural water management and biotechnology, we have an enormous regional economic development opportunity masquerading as a difficult environmental problem. The problems of cultural eutrophication and non-point-source pollution do not lend themselves easily to simple regulatory tools. Unlike Lake Erie—which also suffered phosphorus eutrophication issues in the 1960s and 1970s, but which could be addressed by simple regulatory measures controlling wastewater-treatment-plant effluent—these vast agro-ecological and cultural issues are much less amenable to regulatory approaches.

*The Limits to Growth*, a 1972 book commissioned by the Club of Rome, suggested that resource limitations would, at least eventually, pose limits to growth. One of the authors of that report, Donella Meadows, described "layers of transformation" in the late 1990s (Figure 3) as starting with a change in mindset, *i.e.* seeing a problem for which there is no solution as a major opportunity. All transformation starts with that recognition. The outer rings of transformation involve changing the rules of how the system operates and then monitoring the system and adjusting it as new information is gained.

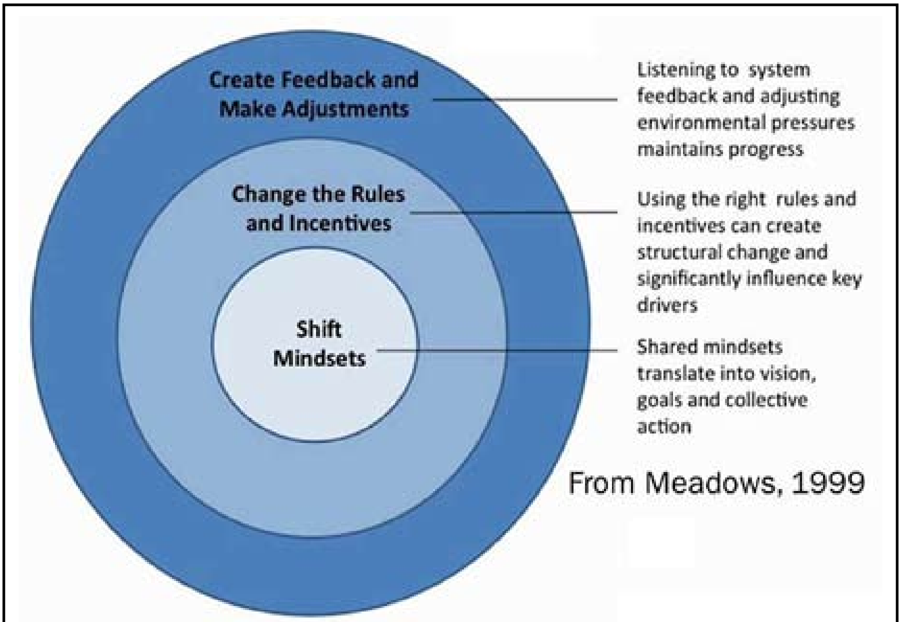



Figure 3. Layers of transformation.

## Climate and Ecosystem Destabilization

The crisis goes beyond Lake Winnipeg. It's a crisis that overlaps with destabilization of regional climate. Figure 4 shows data generated by the Intergovernmental Panel on Climate Change, revealing that the upper part of North America is a climate-change hot spot. This is not a projection, this is the instrumental record since 1901, and we have a rate of temperature increase in the order of 2°C per century. Some data indicate that it's greater than that. Our part of North America is also at a transition zone between sub-humid and semi-arid (Figure 5), implying that climate-change projections will become more variable.

Our ecosystem has been homogenized and atomized; the distribution of landscape features and what we now call ecosystem services have been modified, and many lost. The sectional mile system is similar to that in the United States (Figure 6).

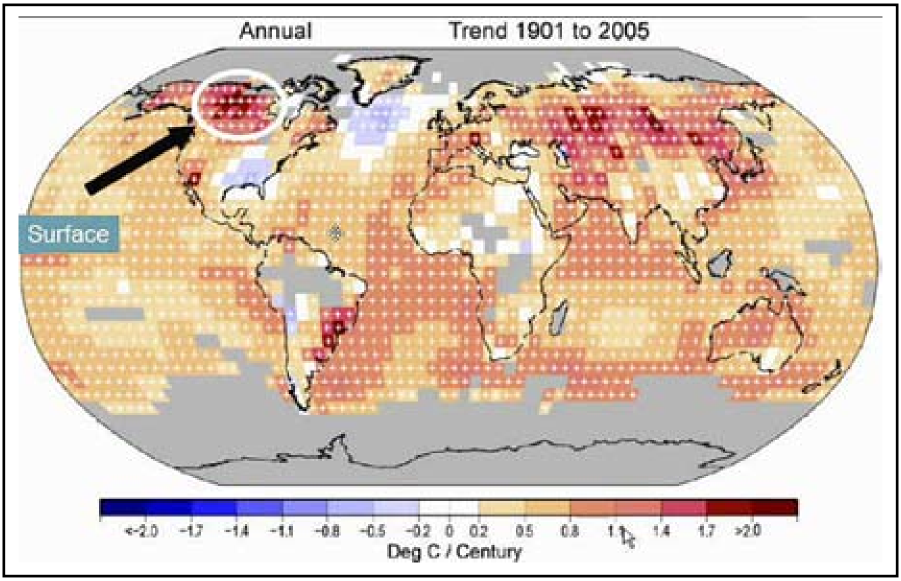



Figure 4. Spatial distribution of temperature increases.

## Correlation of Stresses

Furthermore, stress factors are correlated. Without super sandbags stacked three high against last spring's flood, we would have lost Manitoba's second city, Brandon. And—unprecedented—a dyke on the banks of the Assiniboine River was deliberately breached and agricultural land inundated to minimize flooding in the city of Winnipeg. Also, increasing variability in climate is causing increasingly frequent hydrologic shock, and we know now that that this is correlated with nutrient level; the degree of flooding is exponentially correlated with the mass volume of nutrients that eventually flows downstream to Lake Winnipeg (Figure 7).

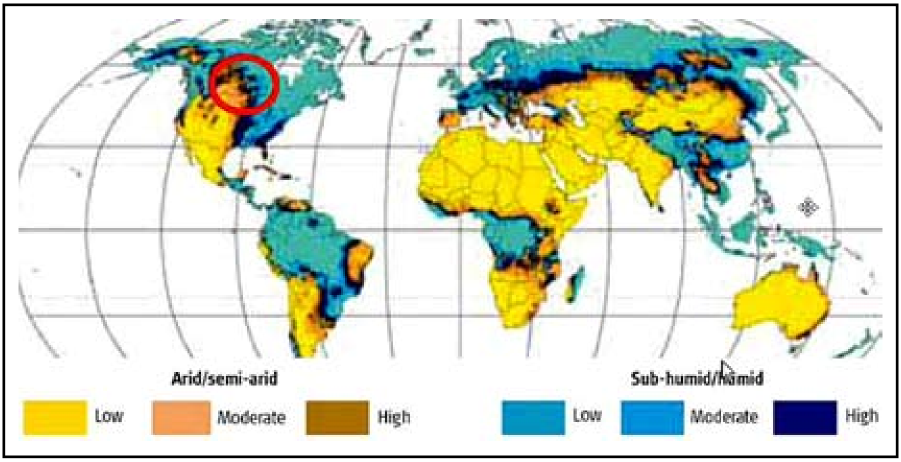



Figure 5. We'll get more extreme.

Figure 6. Landscape conversion for agriculture.

## Phosphate Conundrum

As bleak as this is, I'm going to compound it with messages from the United Nations Environment Program (UNEP) yearbook for 2011, *Emerging Issues in our Global Environment*. They picked up not only on the impact of punishing agroecological systems, but they picked up on the stewardship issue of the depletion of rock phosphate.

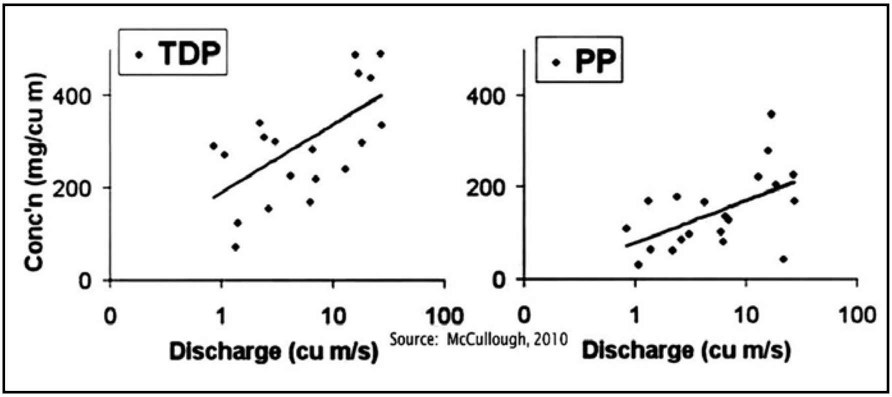



Figure 7. Correlations of concentrations of total dissolved phosphate and particulate phosphate with discharge rate in river water.

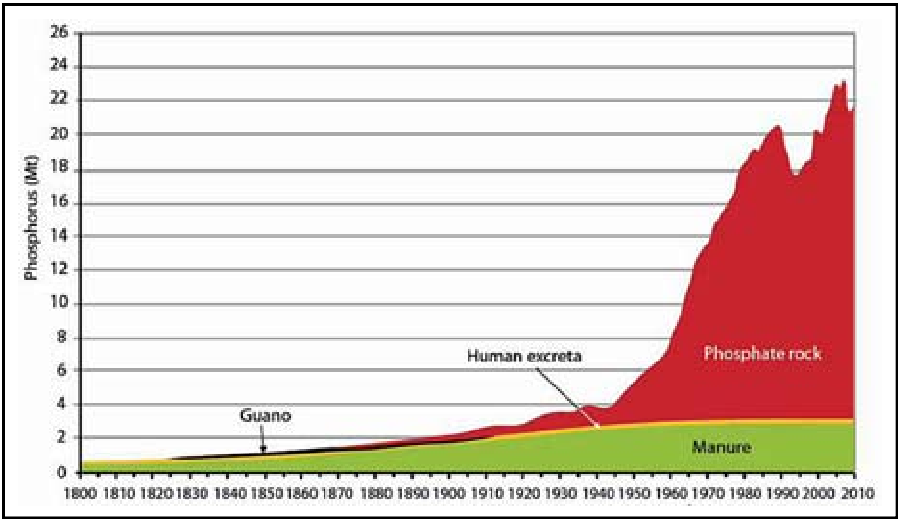



Figure 8. Sources and global consumption and fertilizer P.

A duality exists; phosphorus is at once a noxious pollutant that fouls ecosystems and a scarce strategic asset. Figure 8 shows the hugely increased use of phosphate rock since World War II. Prior to mining of rock phosphate, in the 1800s and early 1900s, the Guano Islands of the South Pacific were major sources of phosphorus that had accumulated as excreta of seabirds. The concern is that rock phosphate is a limited resource. The UNEP yearbook includes a photograph of an algal bloom in Lake Winnipeg as an example of a dysfunctional agroecosystem and, in particular, mismanagement of rock phosphate. We are consuming a scarce mineral resource by continuously reapplying it to agroecosystems—negatively impacting aquatic and other ecosystems downstream—when it could be recycled. It's a precious resource that we are squandering by feeding it to algae.

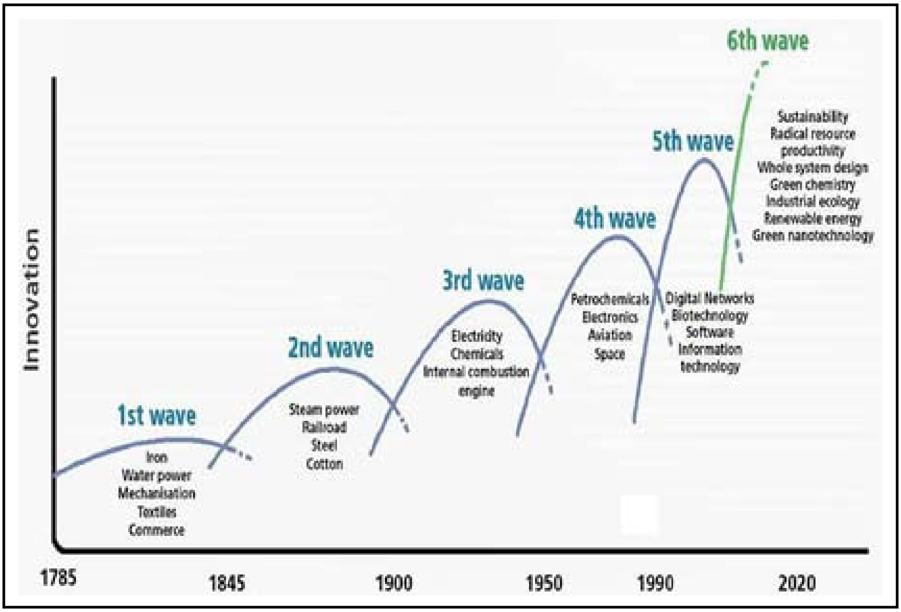



Figure 9. Waves of innovation.

The King of Morocco owns 40% of the world's rock-phosphate assets. China is also a major producer of rock phosphate and, in 2011, they imposed an export tariff as they recognize the strategic value of this resource and its necessity for domestic food production. And UNEP pointed out that:

> *Optimizing agricultural practices while exploring innovative approaches to sustainable use can reduce environmental pressures and enhance the long-term supply of this important plant nutrient.*

## Sixth Wave of Innovation

Futurists may have seen the diagram in Figure 9 before. The speculation is that we are at the take-off point for the sixth wave of innovation. The first wave coincided with the industrial revolution and the harnessing of water-power and development of mechanization, *etc*. The second wave was the development of steam power and railroads, *etc.* And so on. Some say we are witnessing the sixth wave of innovation, characterized by sustainability, rapid resource productivity, whole systems design, green chemistry, industrial ecology, renewable energy and green nanotechnology; in short, this is the bioeconomy. In April, 2012, the White House released a *National Bioeconomy Blueprint* that we are examining carefully in Canada. In February, the European Commission released a communication titled *Innovating for Sustainable Growth: A Bioeconomy for Europe*. The European strategy refers to:

> *…adapt[ing] to and mitigating the adverse impacts of climate change, such as droughts and floods.*

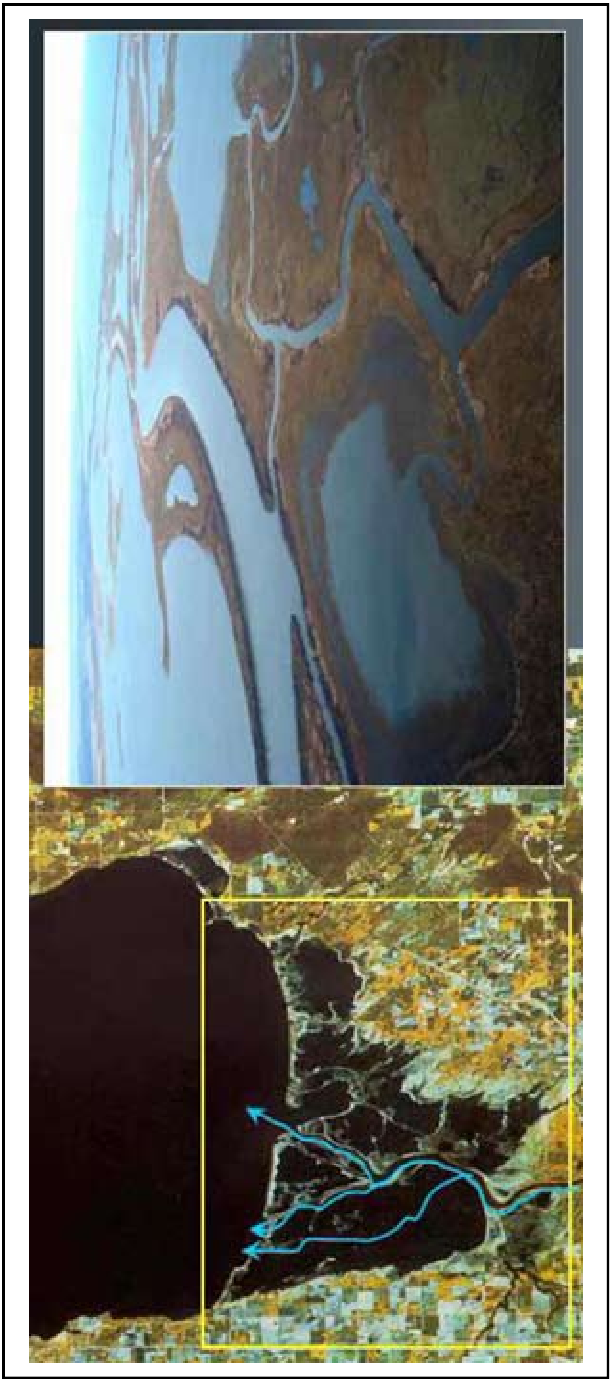


Figure 10. The Netley-Libau Marsh, a freshwater coastal wetland complex on Lake Winnipeg.

Clearly, they are grasping the connection that biotechnology is instrumental to a larger vision of the bioeconomy and, when deployed at ecosystem scale, it can contribute both to climate-change mitigation and adaptation. It's an interesting evolution of the narrative.

That sounds positive, and I'll provide a concrete example. Lake Winnipeg is characterized by two connected oblong basins. At the south end of the south basin, the Red River of the North drains through the Netley-Libau Marsh, a freshwater coastal wetland complex of about 25,000 square kilometers where 60% of the nutrient flow into Lake Winnipeg occurs (Figure 10). This is the river that flooded catastrophically in 1997 when the city of Grand Forks, North Dakota, was inundated and many buildings burned to the ground. The marsh is characterized by an invasive species of cattail.

## Problem Converted to an Oppportunity

We are employing a form of passive ecological engineering. Water flows into and out of the wetlands complex, mixing constantly and creating a hypertrophic system that fosters vigorous growth of the invasive macrophyte, which can be harvested and even baled. It can be densified as a pellet and used as a biofuel to displace coal, for example, with recovery of 90% of the phosphorus in the ash, even without combustion optimization (Figure 11). In short, we are taking a downstream environmental management problem and creating a biomass benefit, a carbon-credit benefit and a habitat benefit for wildlife, and we are stimulating regrowth of the macrophyte by cutting it and allowing better light penetration, and, of course, we are recycling phosphorus. We are transforming a vexing and intractable non-point-source problem into a biomaterials-production opportunity.

We are working with colleagues at the University of Manitoba and the Composites Innovation Center in Winnipeg on higher-value products and alternative uses for the biomass including cellulosic liquid fuels, biocomposites and bioplastics. And we are cooperating with Manitoba Hydro on a biochar demonstration and production of a carbonized coal substitute.


Figure 11. Innovative technology: recapture of phosphorus from harvested cattails.

## Watershed of the Future

We are synthesizing these insights into something we are calling the *Watershed of the Future* (Figure 12). We are integrating hydrologic functions, water-management functions and non-point-source-pollution benefits. Our vision is that, on a watershed basis, well designed distribution of biomass will produce higher levels of ecological *and* economic function. Biomass is the key carrier for diverting nutrients to the biorefinery where we anticipate production of all manner of high-value products ranging from liquid fuels to bioplastics. The key proviso is that we recycle the nutrients because it's a world food-security issue, as well as a source of income.

We have determined that such redesigned watersheds across our landscape, with the biomass-interception function, would enable removal of the phosphorus load on Lake Winnipeg. Furthermore, by producing solid fuels to generate heat, we would have a value chain of several hundred million dollars. If we could deploy bioeconomy technologies on a large scale and produce bioplastics, for example, the potential value chain increases to tens of billions of dollars.

## Bioeconomy Pixel

A disadvantage of the atomized landscape across the Great Plains, discussed above, is that we live with flood episodes and drought episodes because all we do is manage landscape

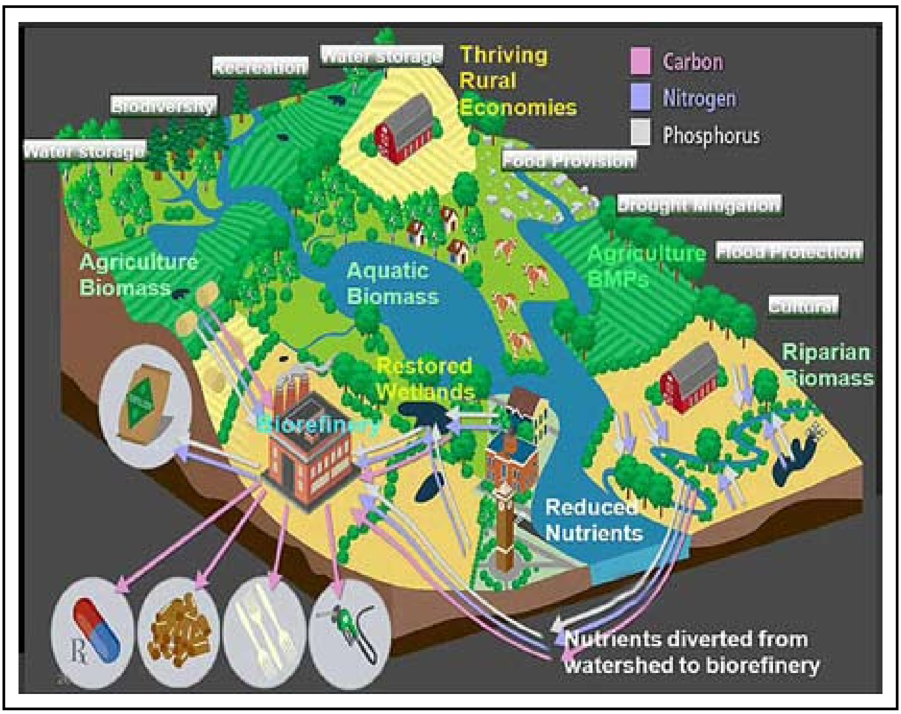



Figure 12. Watershed of the future.

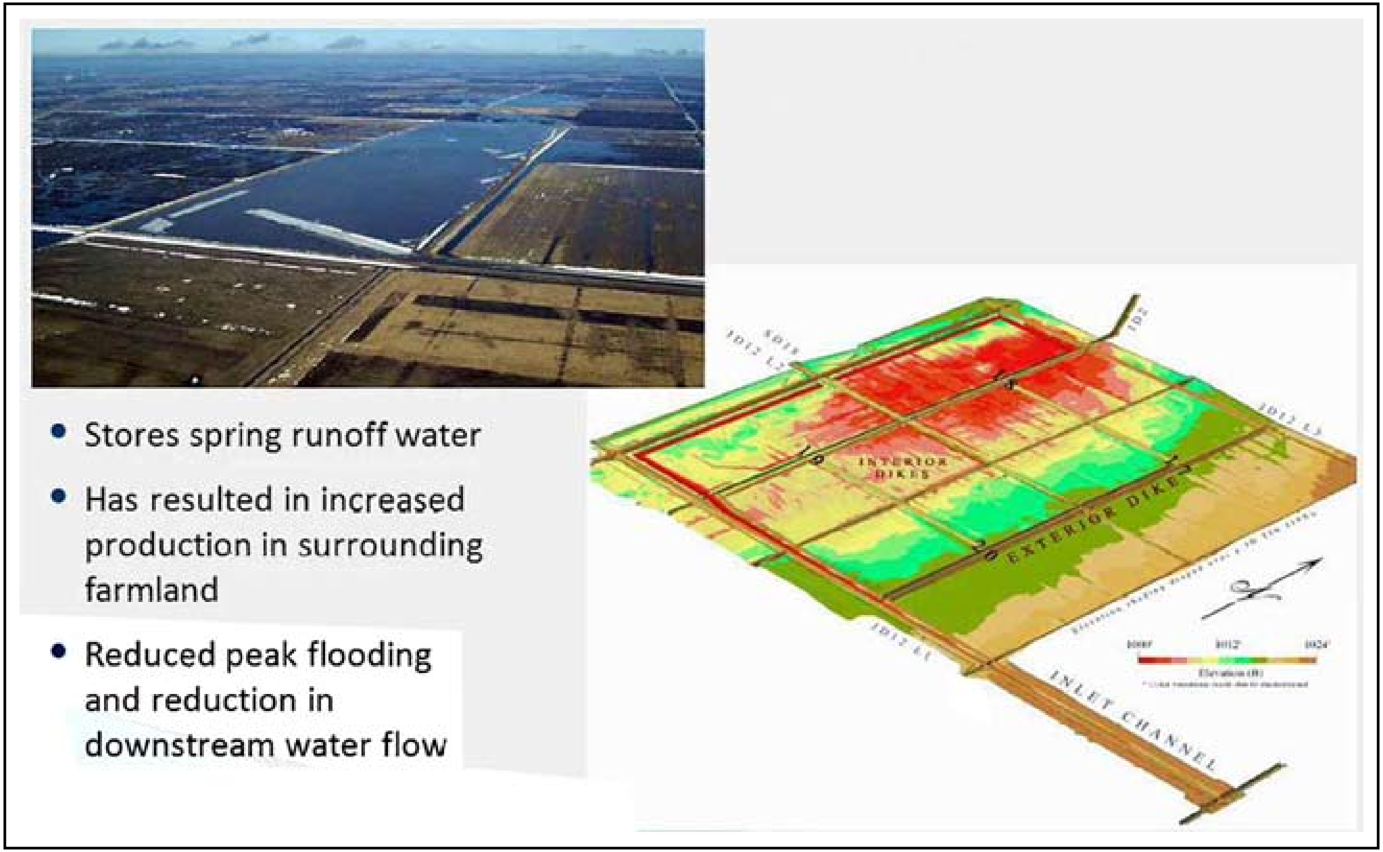



Figure 13. A bioeconomy pixel: the North Ottawa Project, Minnesota.

rather than water, and we have to move past that. Figure 13 shows a possible prototype for consideration: the North Ottawa Project in Minnesota, constructed in the basin of the Red River of the North. It is in an area that is chronically wet. Farms upstream are frequently dysfunctional and farms downstream are frequently flooded. Three sections of land were impounded for the purpose of storing water; it took 20 years for the watershed agency to obtain necessary permits because taking possession of land for seasonal storage was so radical. But now, everyone loves the Project and it is being replicated elsewhere. When I visited in March of 2012, what did I see growing near the twelve corner sections? Cattails. We are working with them to develop biomass/bioenergy capability. We believe that this landscape approach is a practical option for amelioration, adaptation and production of bio-economy value chains.

**HENRY DAVID (Hank) Venema** directs the Water Innovation Centre and Natural and Social Capital Program at the International Institute for Sustainable Development (IISD). He is an engineer with a diverse background. Since 2004, he has led IISD's research on water and agricultural issues in pioneering the application of Natural Capital principles to water-management challenges in Western Canada. In 2009, he led the creation of IISD's Water Innovation Centre with an initial mandate to build a strategic vision for managemen of the Lake Winnipeg Basin based on leading-edge policy, management and technological concepts. The Water Innovation Centre builds upon Lake Winnipeg Basin research work that he has directed at IISD, including ecological goods and service valuation, payments for ecosystem services, decision-support systems for ecosystem investments, water-quality trading, large-scale nutrient capture through ecosystem restoration and watershed management, and innovative governance models for basin management. In 2010, Dr. Venema launched the Lake Winnipeg Bioeconomy Project reframing the issue of lake eutrophication as a regional innovation and economic development opportunity based on the insight that phosphorus—the element regarded as the noxious pollutant responsible for fouling Lake Winnipeg—is, in fact, a scarce and strategic resource that can be captured, recycled and transformed into high-value biomaterial.

# *Technology Approaches to Drought Tolerance at Pioneer*

Dave Warner
*DuPont Pioneer Agricultural Biotechnology*
*Johnston, Iowa*

dave.warner@pioneer.com

Research focused on the improvement of drought tolerance in crop plants has received increased attention in the past ten years. The development of drought-tolerance technologies is one of the most important initiatives for the seed industry in this decade. Increasing worldwide demands for food and agricultural products, combined with fixed amounts of arable land, brought on by increasing global population is driving a need for increased productivity. At the same time, we continue to see evidence of declines in freshwater resources. Public efforts to restrict water usage focus on ways to maintain sustainable water levels in major aquifers and reservoirs. Agriculture, in general, is a major user of freshwater. Approximately 70% of the world's freshwater is used for agricultural purposes.

DuPont Pioneer was the first company to commercialize hybrid maize in 1926. The company has had a dedicated drought-research program since 1957. Due to the company's significant knowledge of maize germplasm, Pioneer focuses drought-tolerance research on maize. Pioneer scientists leverage this research to other crops.

## Multiple Product Options

Drought affects crops differently depending on the geography and stress factors of each unique environment. Depending on the timing and severity of drought episodes, yield losses due to drought in maize can be quite severe. Pioneer has been a leader in the development of drought-tolerant corn hybrids and utilizes a multi-phase research approach that delivers total product performance minimizing risk and maximizing productivity. Growers today are already experiencing the benefits of DuPont Pioneer hybrids, which deliver a yield advantage in water-limited environments, and offer top-end yield potential under optimal growing conditions, allowing growers to help minimize risk and maximize productivity on every acre.

In the past decade, many new technology opportunities have emerged to aid researchers in the improvement of drought tolerance, including marker-assisted breeding tools, transgenic solutions and new agronomic practices. The successful approach to improvement of drought tolerance in maize involves an integrated approach that couples strong base genetics, developed from years of success in conventional breeding, with leading-edge technologies and state-of-the-art agronomic practices. Farmers need multiple product options that are best adapted to their specific environments coupled with advice on the latest agronomic practices to maximize performance.

## Resource Integration

Drought tolerance is a complex trait that is influenced by many plant processes. A simple diagram of how water cycles through the environment and how the plant integrates resources that contribute to productivity is shown in Figure 1. Plant productivity, under drought stress, is determined by the interaction of water capture, water-use efficiency and water partitioning within the plant. Research strategies focused on improvement of drought tolerance need to integrate all of these factors.

## Optimum AQUAmax

Drought-tolerance research at Pioneer focuses on a multi-pronged approach that involves conventional plant breeding, and native- and transgenic-trait technologies. For over 50 years, our conventional breeding programs have been improving drought tolerance. More recently, we've taken advantage of molecular-marker tools and whole-genome models to select native maize traits that are important for drought tolerance. Using this technology, we have launched a product line under the brand Optimum® AQUAmax™. When evaluated in 680 water-limited environments in 2011, Optimum AQUAmax hybrids demonstrated greater than 7% yield advantages on-farm when compared to grower-selected competitor hybrids. In 7,258 on-farm comparisons under more favorable growing conditions, Optimum AQUAmax hybrids demonstrated a 3.4% yield advantage over commercially available competitor hybrids. This indicates Optimum AQUAmax products help minimize risk and maximize productivity on every acre.

## Robust Research

As we look into the next decade, we have a very strong and robust research pipeline of transgenic traits that will provide additional levels of tolerance to our conventional and native approaches. Discovery approaches start with thousands of different lead genes that come from many different sources. In most cases, lead discovery screening is accomplished with high-throughput assays, using model systems in controlled environments. A subset of these gene leads are transformed into the target crop for advanced product testing. Field testing under both drought-stressed and non-stressed conditions is conducted over multiple seasons to evaluate candidate genes for yield and other important agronomic traits.

All potential Pioneer products developed from the drought-tolerance program are evaluated in an extensive network of field-testing sites that include both managed-stress and target-market locations. Managed-stress locations are located in environments with very

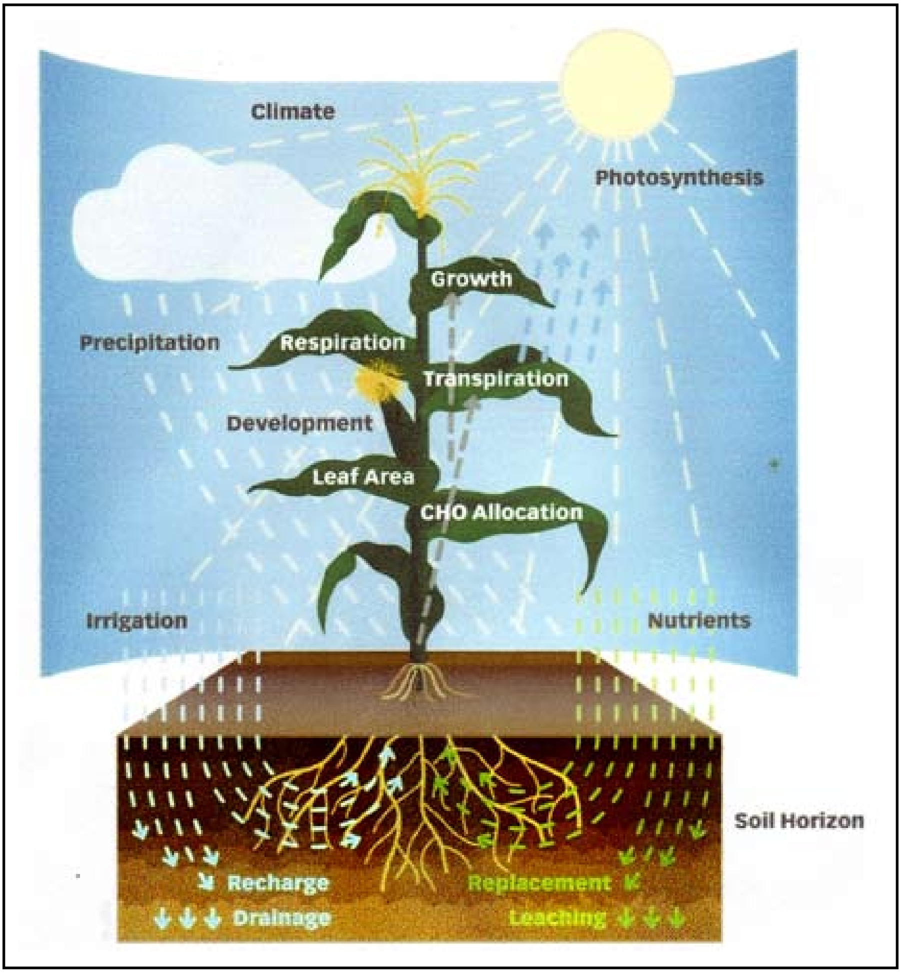


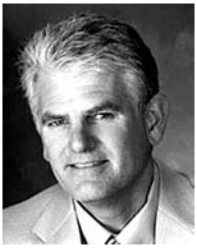

Figure 1. Environmental resource cycles and their involvement in plant productivity.

low rainfall and use precision-irrigation technologies to control the intensity, duration and timing of stress episodes. Target-market locations are used to evaluate the performance of lead products in the environments where they will be sold. Our Enclass® environmental modeling system assists in the placement of the right hybrid product on the right acre.

Many factors contribute to increased productivity. In light of this, Pioneer extensively evaluates the performance of our products using many different agronomic practices, including plant populations, soil fertility and water management. We use this information to support our customers with the best agronomic recommendations for use with our drought-tolerance technologies. The best combination of products and agronomic practices leads to the best real improvements under drought stress.

## Committed to Collaboration

To advance the best innovations, we are committed to collaborating with both public and private organizations. We leverage these relationships to discover new approaches to drought tolerance and to test our existing technologies, globally, to make sure we make the best possible product-advancement decisions. The application and development of these innovative drought technologies have already addressed, and will continue to address, the wide range of water-supply environments around the world and will continue to improve productivity across crops and regions to ensure we meet the demands of a growing world population.



**Dave Warner** is currently Agronomic Traits program leader within the Agricultural Biotechnology Division of Pioneer Hi-Bred International. He is responsible for cross-functional program management and research strategy for all Pioneer drought-tolerance and nitrogen-use efficiency technology programs. He joined Pioneer in May 2010 with extensive experience in maize drought-stress tolerance, crop physiology, genetics and remote sensing. Prior to joining Pioneer, he held various research leadership positions within Monsanto and Dekalb Genetics, most recently as a science fellow. His work led to the discovery and development of several transgenic and native-trait technology solutions to water sustainability in maize production.

Warner, who holds degrees from the University of Massachusetts and the University of Illinois, is an inventor on several patents, and an author of many publications and presentations on drought-tolerance and remote-sensing technologies. He has worked with academic, industry and NGO collaborators in North and South America, India and Africa.

# *We Can Now Solve the 10,000-Year-Old Problem of Agriculture*

Wes Jackson
*The Land Institute*
*Salina, Kansas*

jackson@landinstitute.org

My beginning fix on native prairie happened during the summer of 1952 when I was sixteen. I worked on a ranch near White River, South Dakota, close to the Rosebud Indian Reservation, and lived in the shack pictured in Figure 1. Years later, I began to grasp the importance of nature's ecosystems. It happened in my own state of Kansas, where we have thousands of acres of prairie ranging from tall to short grass (Figure 2). One June day in 1977, two friends and I visited a tallgrass prairie in the Flint Hills after a drenching rain. On the way home, we saw farmers' fields similar to the one in Figure 3.

On the prairie (Figure 2), nature's ecosystem is resilient and more or less free of damaging erosion, unlike grain agriculture (Figure 3). Why this is so has to do with what lies below the surface. Figure 4 reveals a network of perennial roots of various structures in prairie soil, whereas Figure 5 provides a contrast between perennials and annuals of closely related species, both in monoculture. On the left is perennial wheatgrass, which we have named Kernza™. On the right is common annual bread wheat.

## Herbaceous Perennials

How does a farmer manage herbaceous perennial seed-producing polycultures? We can take a clue from the native prairie, still in existence, as our standard. Nature uses fire as one "management tool" (Figure 6) and grazing as another, as exemplified by bison on The Land Institute prairie (Figure 7).

Since most farmers are disinclined to produce bison, the domestic bovine is a close enough analog (Figure 8, Flint Hills). The domestic alternative, like its wild relative, is a selective grazer.

A non-selective "grazer" is the mowing machine (Figure 9).

Figure 1.

Figure 2.

Figure 3. (courtesy of Andy Larson)

Figure 4. (courtesy of Jim Richardson)

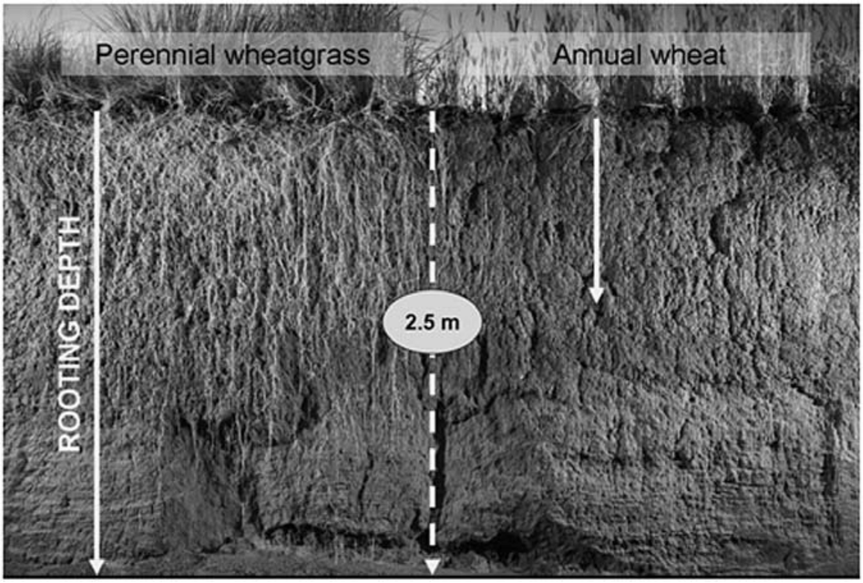



Figure 5.

Figure 6. (courtesy of Jim Richardson)

Figure 7.

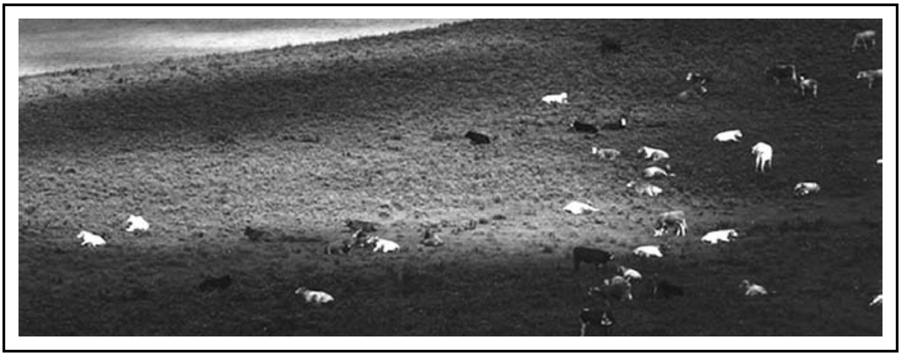


Figure 8. (courtesy of Jim Richardson)

Figure 9. (courtesy of *The Draft Horse Journal*)

When we combine fire with selective and non-selective grazers, we see the potential for future management tools.

Such agriculture, admittedly, would be a radical departure from what farmers have done for the past 10,000 years, but the necessity for something different in the way we interact with the land can be seen from various points of view. For example, the Millennium Ecosystem Assessment (2005), sponsored by the United Nations, concluded that agriculture is the "largest threat to biodiversity and ecosystem function of any single human activity."

But there is promising news. Ecologist Chris Field (2001), writing in *Science*, concluded from a survey of the earth's ecosystems that, "In most parts of the world, human activities, and agriculture in particular, have resulted in decreases in net primary productivity from the levels that likely existed prior to human management."

For nearly three and a half decades, The Land Institute has addressed "the problem of agriculture" by mimicking nature's ecosystems. We do so with herbaceous perennials in mixtures. The first step is to breed perennial grain-producing crops. Dr. Shuwen Wang, a molecular geneticist at The Land Institute is working to develop perennial wheat. Dr. Stan Cox is developing a winter-hardy perennial sorghum. Dr. David Van Tassel is working on perennial sunflowers as well as a perennial legume known as Illinois bundleflower. In addition, The Land Institute provides financial support to Dr. Hu Fengyi, who is developing a perennial upland rice for steep hillsides in China and elsewhere, where soil erosion is extreme. Good progress is being made on all fronts by these breeders.

Once we move our minds to consider perennial polycultures, our imagination then leaps to new possibilities. To help with this leap, consider Figure 10, with the hierarchy reaching from the ecosphere to the atom.

| | | |
|---|---|---|
| • Ecosphere | — | Whole Earth |
| • **Ecosystem** | — | **Prairie, Rainforest, etc.** |
| • Organisms | — | Humans, Dogs, etc. |
| • Organs | — | Liver, Heart, etc. |
| • Tissues | — | Muscle, |
| • Cells | — | Any |
| • Molecules | — | DNA, Protein |
| • Atoms | — | Carbon, Nitrogen, etc. |

Figure 10.

After ecosphere is ecosystem, a slab of space/time that includes both the biotic and the physical. It should be clear to all that countless ecosystem processes that function in the wild are greatly limited in annual monocultures, which is akin to clear-cutting a forest every year; the chance for many processes in the wild to return to the land is greatly reduced. But with perennials on the horizon, what ecologists have been learning over more than a century can begin to be applied to grain production.

This idea is gaining traction. In 1997, an international conference in Australia was devoted to the theme of *Agriculture as a Mimic of Natural Ecosystems* and a proceedings volume was published (Lefroy *et al.*, 1999). Since then, global research to develop perennial grains has expanded. Most of the germplasm derived from our scientists' efforts at The Land Institute is in the hands of researchers in Australia, Canada, Nepal, China and elsewhere in the United States. This spread of interest and research has led to the validation of the desirability of perennial grains by the National Research Council (2010) of the National Academy of Science:

> *Perennial plants reduce erosion risks, sequester more carbon, and require less fuel, fertilizer, and pesticides to grow than their annual counterparts.*

And the Royal Society (2009) provided a similar endorsement:

> *Perennial crops would store more carbon, maintain better soil and water quality and would be consistent with minimum till practice. These crops would also manage nutrients more conservatively than conventional annual crops, and they would have greater biomass and resource management capacity.*

Conventional thinking leads to saying that if we are to preserve biodiversity, we will have to intensify agriculture. The typical language of dualism says "production at the expense of conservation" or "conservation at the expense of production." Instead, we can now imagine "conservation as a consequence of production."

## Preeminence of Grains

On the table for us to consider are not forests or range lands. Nor are vegetables and fruits. On the table are grains, because they are the source of 70% of our calories. Grains have long been central. A 1565 painting by Peter Bruegel (Figure 11) shows that nearly 100% of the agricultural landscape was devoted to grain production. Even the trees—apple and pear here—have their lower limbs removed to allow light through to foster crop growth.

Figure 12 shows the distribution of crops grown in the United States.

## In Summary

If we are to solve the 10,000-year-old problem of agriculture, the most predominant feature of which has been soil erosion, we will need to develop perennial grains. If we are to adequately manage insects, pathogens and weeds as well as biological nitrogen fixation, we will need polycultures.

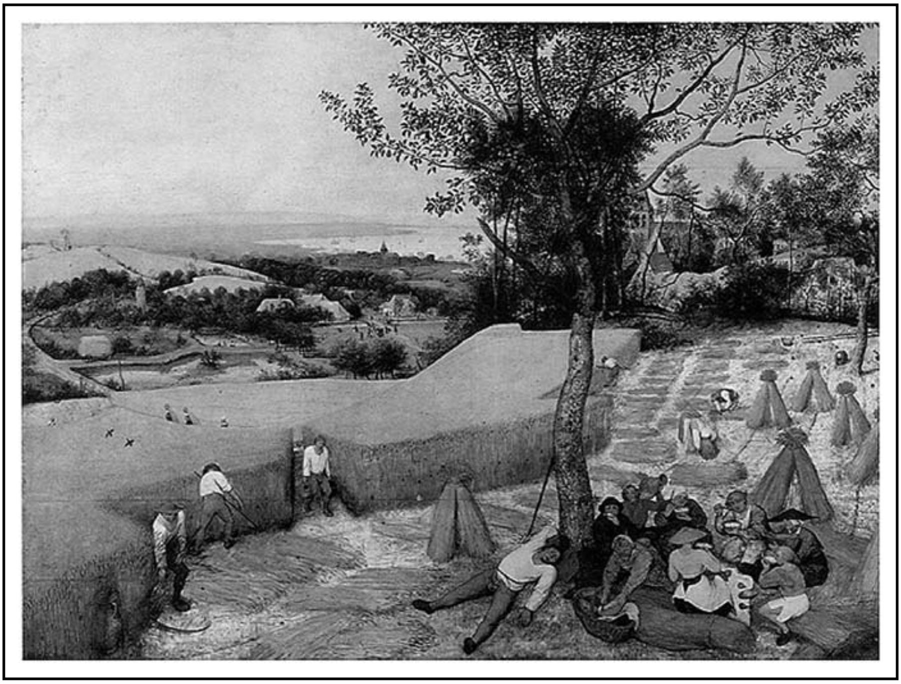


Figure 11

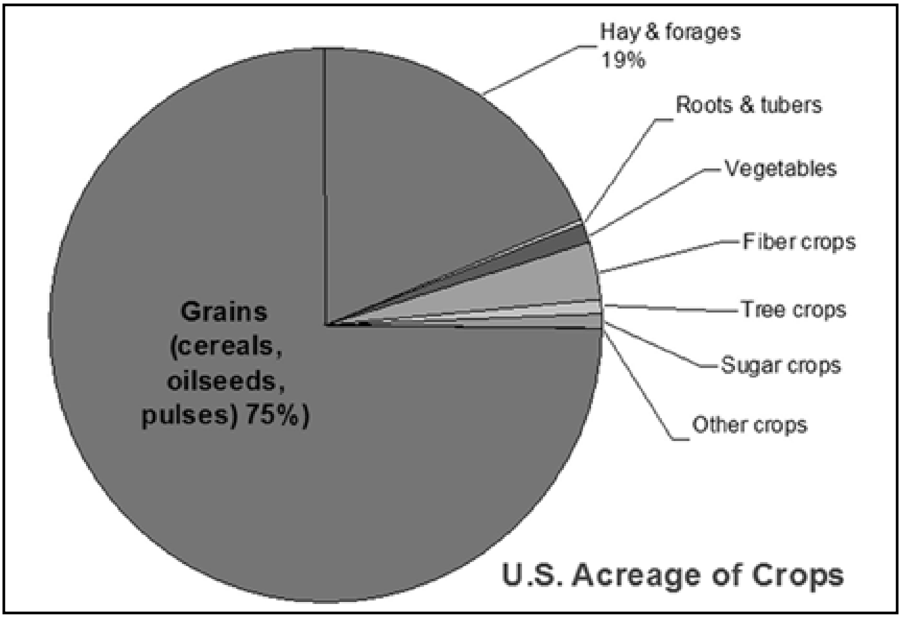



Figure 12.

## References


Field C (2001) Sharing the Garden. Science 294 2490–2491.

Lefroy EC *et al.* (1999) Agriculture as a Mimic of Natural Ecosystems. New York: Springer.

Millennium Ecosystem Assessment (2005) Ecosystems and Human Well-Being: Current State and Trends, Chapter 26. Washington, DC: Island Press.

National Research Council (2010) Toward Sustainable Agricultural Systems in the 21st Century. Washington, DC: The National Academies Press.

The Royal Society (2009) Reaping the Benefits. London: The Royal Society.


**WES JACKSON** earned a BA in biology from Kansas Wesleyan, an MA in botany from the University of Kansas, and a PhD in genetics from North Carolina State University. He established and served as chair of one of the country's first environmental studies programs at California State University-Sacramento and then returned to his native Kansas to found The Land Institute in 1976. *LIFE* magazine named him as one of eighteen individuals they predicted would be among the 100 "important Americans of the 20th century." In 2005, *Smithsonian* named him one of "35 Who Made a Difference," and in 2009 he was included in *Rolling Stone*'s "100 Agents of Change." Work of The Land Institute has been featured extensively in the popular media, including *The Atlantic Monthly*, *Audubon*, *National Geographic, Time Magazine, The MacNeil-Lehrer News Hour*, and *All Things Considered* on National Public Radio. Dr. Jackson is a recipient of the Pew Conservation Scholars award (1990), a MacArthur Fellowship (1992), a Right Livelihood Award (Stockholm)—known as the" Alternative Nobel Prize" (2000)—and the Louis Bromfield Award (2010). His writings include the recent works, *Nature as Measure* (2011) and *Consulting the Genius of the Place: An Ecological Approach to a New Agriculture* (2010).

# *Evaluation of Drought-Tolerance Strategies in Cotton*

Randy D. Allen
*Oklahoma State University*
*Ardmore, Oklahoma*

randy.allen@okstate.edu

Research made possible through the use of the wealth of genomic information and genetic resources available for model plant species such as *Arabidopsis thaliana* has led to a substantial increase in our knowledge about how plants respond to stressful environmental conditions. This leap in understanding provides the basis for many new strategies for optimization of stress tolerance in crop plants through both traditional and transgenic approaches. Although, to date, most of these strategies have been tested only in model plants, evaluation of some of them in important crop species, including cotton, is now underway. Application of novel stress-tolerance technologies will require extensive physiological and agronomic evaluation of plants that express these genes to determine their ultimate applicability to crop systems. A broad-based evaluation strategy for candidate genes will be necessary to test their value under a wide variety of field conditions. In cotton, this will include testing the effects of candidate genes on germination, seedling survival and stand establishment, vegetative growth and the transition to flowering, flowering period, boll maturation, and fiber development and quality. Though experiments in model species are valuable, experience shows that they do not guarantee similar results in a heterologous crop species. Our preliminary work with transgenic cotton plants that express transcription factors, such as ABF3 and CBF3, show that optimization of expression patterns using different promoters or other regulatory strategies will be necessary. The recent identification of complex post-transcriptional and post-translational regulatory mechanisms for stress-responsive gene expression reinforces the need for direct testing of new technologies in crop species. These mechanisms are able to fine-tune the expression of stress-responsive genes by ensuring their suppression under non-stressful conditions and attenuating stress responses in the face of prolonged stress exposure. However, since these mechanisms can be sequence-specific, we anticipate that, in some cases, different results will be achieved in plants depending on whether endogenous or heterologous coding sequences are used.

The translational genomic approach, in which the depth of knowledge gleaned from a model system is systematically translated to economically important crop plants that are less amenable for basic research, is a powerful strategy for crop improvement. Although it may not yet be possible to accurately predict the outcome of any particular transgenic experiment, the ability to narrow the group of candidate genes based on experimental data from model species makes it possible to approach these experiments in a much more rational way. As our understanding of the complex regulatory networks that control stress-responsive gene expression develops and the roles of these regulatory mechanisms in plant productivity are revealed, it is likely that substantial increases in crop yield under suboptimal conditions can be realized.

## Abiotic Stresses

Water deficit, salinity, and temperature extremes are the primary factors that limit crop productivity, accounting for more than a 50% reduction in yields worldwide (Boyer, 1982). Approximately 22% of agricultural land is saline (FAO, 2004) and drought-affected areas are expanding and this trend is expected to accelerate (Burke *et al.,* 2006). Growth of the human population combined with increasing prosperity in developing countries and a decrease in arable land are creating greater demands for food, fiber, biomaterials, and sustainable agriculture (Ragauskas *et al.*, 2006). A large proportion of available fresh water is consumed by agriculture and drought is a perennial environmental constraint, affecting approximately 25% of all crops worldwide at enormous cost. For example, dry-land cotton crops are decimated by drought on a regular basis and estimates of the value of cotton varieties with increased photosynthetic and water-use efficiencies, enhanced flowering, and improved seed qualities exceed $1 billion/yr in the United States, and $5 billion/yr globally (Wilkins *et al.*, 2000). The task of identifying gene functions and developing effective strategies to use these functions for crop improvement is daunting and a more complete understanding of these mechanisms is needed to achieve the promises of plant biotechnology.

Drought induces a wide range of plant responses, including stomatal closure, changes in gene expression, accumulation of abscisic acid (ABA), production of osmotically active compounds, and the synthesis of protective proteins that scavenge oxygen radicals or act as molecular chaperones (Wang *et al.*, 2003). These responses are controlled by molecular networks that activate stress-responsive mechanisms to re-establish homeostasis and protect and repair damaged cellular components (Ramachandra-Reddy, 2004). Abiotic-stress responses are genetically complex and, thus, difficult to manipulate. Early experimental strategies for engineering abiotic-stress tolerance in plants relied largely on the expression of genes that encode protective molecules such as dehydrins and antioxidant enzymes or on enzymes involved in the synthesis of functional and structural metabolites (for examples, see Roxas *et al.*, 2000; Kornyeyev *et al.*, 2001; Payton *et al.*, 2001; Park *et al.*, 2005). More recently, strategies to use genes that are involved in signaling and regulatory pathways have shown great promise (Umezawa *et al.*, 2006).

Development of transgenic strategies by the introduction of selected genes provides a focused approach for the improvement of abiotic-stress tolerance in plants. Genetic engineering allows the transfer of genes from any source, including non-plant species and permits the expression of the introduced genes to be controlled both temporally and spatially. This capability can be critical if expression of a given gene is needed only at a defined developmental stage, in a certain organ or tissue, or in response to specific environmental conditions. Although promoters that are constitutively expressed at high levels are still widely used, they are not appropriate for all transgenes. This is especially true for stress-responsive genes, which often have serious deleterious effects when constitutively expressed. Therefore, transgenic modification provides a wide variety of options for the development of novel strategies for crop improvement.

In addition to the technology used to generate transgenic plants that express their introduced genes in an appropriate way, it is also important to evaluate these transgenic plants such as to determine the effects of the introduced gene on stress-tolerance characteristics. In many cases, transgenes have been tested only in model-system plants such as arabidopsis [*Arabidopsis thaliana* (L.) Heynh.] or tobacco (*Nicotiana tabacum* L.). While these "proof-of-concept" experiments can give important clues about the potential usefulness of specific genes in plants such as cotton, much of the published work depends on artificial environments that are unlike those faced by crops under field conditions. In addition, physiological characterization often does not extend beyond evaluation of growth or survival under severe conditions. Therefore, rigorous physiological evaluation of the tolerance of transgenic crop plants to abiotic stresses and the effects of specific transgenes on agronomic traits such as yield and quality are needed. In the paragraphs below, I briefly summarize recent progress in the understanding of stress-responsive regulatory pathways in plants and the evaluation of these mechanisms for their potential utility in the improvement of abiotic-stress tolerance, with emphasis on drought, salinity and temperature extremes. I also outline, where possible, the published and preliminary experiments in which transgenic modification of stress tolerance in cotton has been attempted.

## Plant Stress Responses

Much has been learned about the role of specific stress-protective genes in determining stress-tolerance phenotypes through experiments in transgenic plants. Many of the transgenic plant lines produced show detectable increases in tolerance to specific or, sometimes, multiple stresses under laboratory conditions. However, in only a few cases have the effects of these genes been tested in the field. Although promising, the levels of stress tolerance provided from the transfer of a single gene encoding a specific stress-protective protein may not reach the levels necessary to justify incorporation into a commercial variety. Doubts about whether the resulting improvement in stress tolerance is of sufficient magnitude to provide an appreciable improvement in the performance of a certain crop under field conditions make it difficult to justify the huge financial investment necessary to bring a transgenic variety to market. Thus, efforts have more recently focused on functional evaluation of genes that play crucial roles in the regulation of native stress responses in plants. These experiments provide important new understanding of the complex regulatory networks that plant cells use to sense and respond to stressful conditions and provide additional opportunities for the use of transgenic strategies to alter plant-stress responses that may provide stress-tolerance traits that are sufficiently robust to justify commercial investment.

### *Transcription Factors*

Genetic dissection of plant signal transduction has provided an important framework for the development of a more complete understanding of the complex signal-transduction pathways that regulate plant responses to abiotic stress. Due to amenability of analysis, genetic characterization of plant-stress responses has focused primarily on arabidopsis. These efforts have identified diverse classes of transcription factors that are associated with stress-responsive gene expression, including the MYC/MYB, basic leucine zipper domain (bZIP), homeodomain leucine zipper (HD-Zip), nuclear factor Y (NF-Y), ABI3/VP1, WRKY, and various zinc-finger protein families.

Considerable overlap exists between the signal-transduction events that occur during exposure to cold and drought stress (for reviews, see Shinozaki *et al.*, 2003; Zhang *et al.*, 2004). Some of these processes are regulated by abscisic acid (ABA), whereas others appear to be ABA independent. For detailed reviews of the regulation of gene expression by ABA, see Finkelstein *et al.*, (2002); Himmelbach *et al.*, (2003); Kuhn and Schroeder (2003). ABA-response elements (ABREs) are located upstream of many ABA-responsive genes. These *cis*-acting elements interact with a class of bZIP transcription factors known as ABFs. Promoters with optimal ABA responsiveness often contain a second *cis*-acting element (Shen and Ho, 1995) that is similar to a C-repeat/dehydration-responsive element (CRT/DRE). Thus, ABRE-binding bZIP proteins and CRT/DRE-binding AP2 factors (CBF/DREB1) may interact to control gene expression in response to ABA, osmotic stress and cold temperatures (Narusaka *et al.*, 2003) (Figure 1).

Constitutive expression of the ABA-dependent bZIP transcription factors ABF3 or ABF4 in arabidopsis resulted in up-regulated expression of several ABA/stress-responsive genes including *RD29B, RA18*, *ABI1* and *ABI2*, leading to enhanced drought tolerance (Kagaya *et al.*, 2002; Kang *et al.*, 2002). Constitutive over-expression of ABF2 in arabidopsis also resulted in other ABA-associated phenotypes, including hypersensitivity to ABA and sugar and stunted growth (Kang *et al.,* 2002). However, expression of the arabidopsis *ABF3* gene in rice and lettuce under control of the constitutive *Ubiquitin 1* promoter from maize resulted in enhanced drought tolerance without negative effects on plant growth and development (Oh *et al.,* 2005; Vanjildorj *et al.,* 2005).

Based on these successful examples, transgenic cotton plants with increased expression of arabidopsis ABF3 were created in our laboratory (L. Aleman, H. Abdel-Mageed, R.D. Allen, unpublished data). Our preliminary observations indicate that transgenic cotton plants that constitutively express ABF3 under control of the CaMV 35S promoter exhibit enhanced expression of ABA-responsive genes under non-inductive conditions and show enhanced survival under severe water deficit (Figure 2). However, these plants also exhibit deleterious side-effects including reduced vegetative growth and delayed flowering. The relatively severe negative effects associated with constitutive expression of

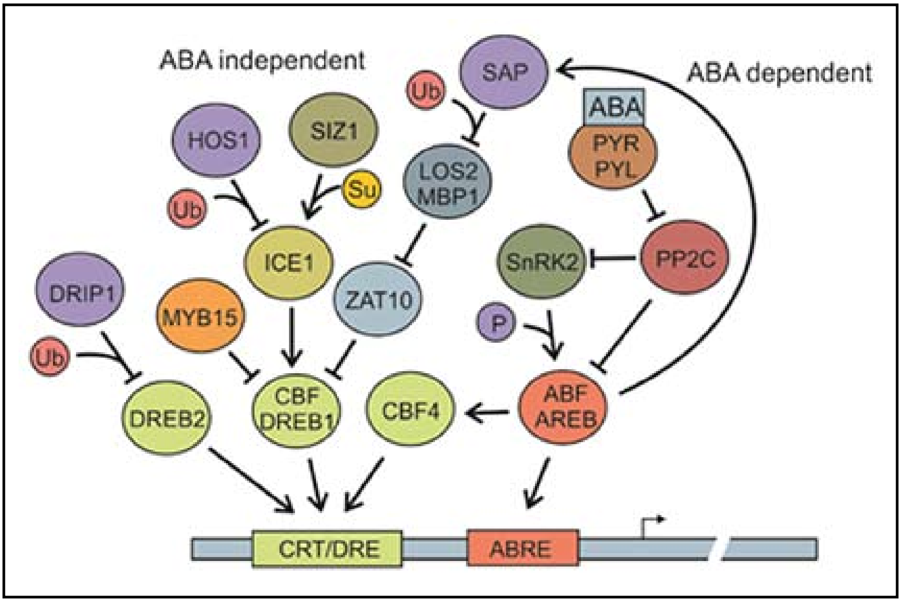



Figure 1. Simplified model for the transcriptional and post-transcriptional regulatory mechanisms that mediate stress-responsive gene expression in plant cells. Upstream regulatory sequences of many stress-responsive genes carry *cis*-acting sequences that bind stress-regulated transcription factors. In this model, ABA-dependent activation is mediated via ABF/AREB transcription factors, whereas ABA-independent responses are controlled by CBF/DREB1 factors. Under normal conditions, transcription of *CBF* genes is suppressed by MYB15 and the zinc-finger transcriptional regulator ZAT10. Levels of the transcriptional activator protein ICE1 remain low under these conditions due to HOS1-dependent ubiquitination and degradation. Stress exposure leads to stabilization of ICE1 thorough SIZ1-dependent sumoylation.[1] In contrast, activation of the ABA-responsive ABF/AREP transcription factors is mediated primarily through a protein phosphorylation/dephosphorylation cascade. Under normal conditions, ABFs are maintained in the inactive non-phosphorylated state. Binding of ABA to the ABA receptor (PYR/PYL) inactivates PP2C protein phosphatases that prevent auto-phosphorylation of SnRK2 protein kinases. Activation of SnRK2s leads to phosphorylation of ABF. In this hypothetical example, crosstalk between these ABA-dependent and ABA-independent pathways can occur through the ABA-responsive expression of genes that encode CBF4 and SAP ubiquitin ligases. SAPs may target the LOS2 MBP-1-like transcriptional repressor. Expression of stress-protective genes by the CBF/DREB1 and ABF/AREB signaling pathways is controlled by a complex web of transcriptional and post-transcriptional regulatory mechanisms. Each of these regulatory steps provides an opportunity for the development of novel strategies for the genetic optimization of stress tolerance in plants.

---

[1]Defined on page 53.

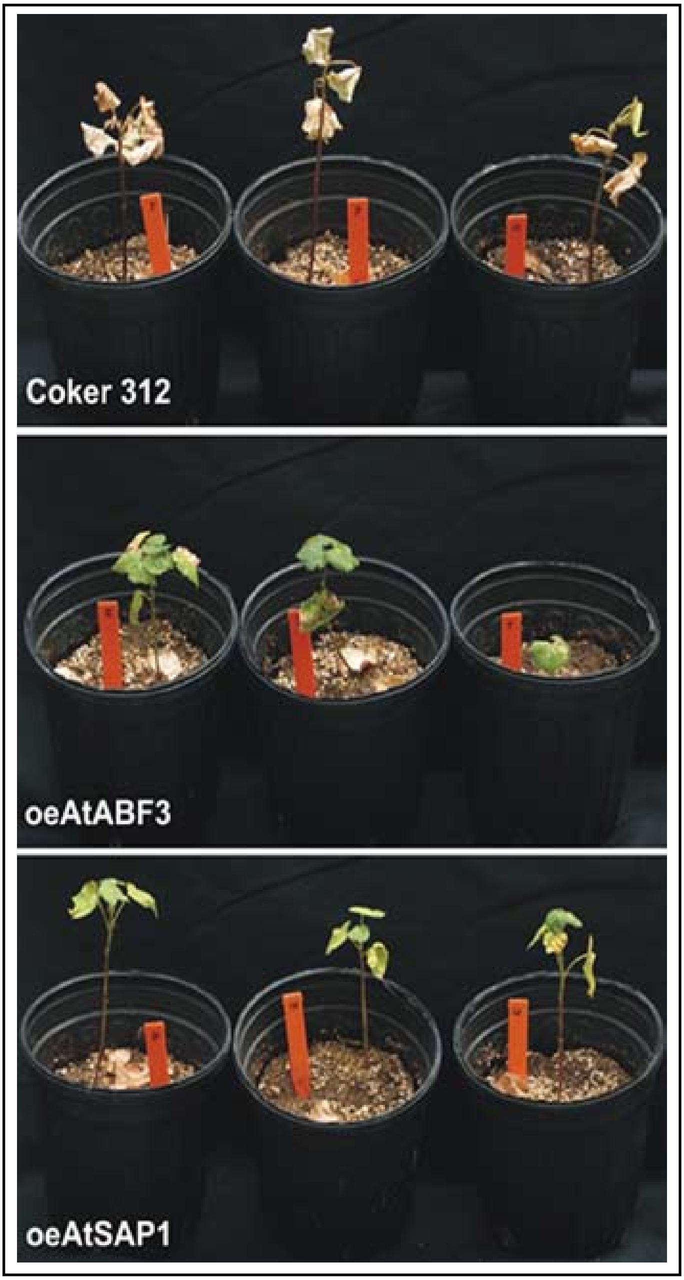



Figure 2. Comparison of water-deficit survival of greenhouse-grown wild-type cotton plants (Coker 312) and transgenic cotton plants that constitutively express either AtABF3 or AtSAP1. Plants were grown with ample moisture to the 5$^{th}$ leaf stage then water was withheld until the wild-type plants reached terminal wilt. The plants were re-watered one day before they were photographed. Wild-type plants were dead after this severe water-deficit exposure whereas plants of both transgenic genotypes survived and recovered from the stress treatment.

ABF3 in cotton led us to conclude that it responds too strongly to this foreign transcription factor. Therefore, development of transgenic plants using native *ABF* genes or in which *ABF3* expression is controlled by stress-responsive promoters may be required if this gene is to be used to improve stress tolerance without negative impacts on yield and other properties. Cotton plants that express these stress-responsive *ABF3* transgenes are now being tested.

Cold acclimation in arabidopsis involves the cold-responsive expression of a large number of genes, many of which are regulated by the *CBF/DREB1* regulon (Thomashow, 1998). *CBF/DREB1* genes in arabidopsis are expressed at low levels under normal growth conditions, but their expression increases within minutes after exposure to cold or drought stress. This gene family includes *CBF1*, *CBF2* and *CBF3* genes (Gilmour *et al.*, 1998; Medina *et al.*, 1999; Jaglo *et al.*, 2001), also known as *DREB1B*, *DREB1C* and *DREB1A*, respectively (Liu *et al.*, 1998). These genes encode transcriptional activators that bind to the conserved CRT/DRE DNA elements located in the promoters of certain cold-responsive genes (Baker *et al.*, 1994; Yamaguchi-Shinozaki *et al.*, 1994; Stockinger *et al.*, 1997; Gilmour *et al.*, 1998). Ectopic expression of these transcription factors in transgenic plants led to elevated freezing tolerance without prior cold treatment (Jaglo-Ottosen *et al.*, 1998; Liu *et al.*, 1998; Gilmour *et al.*, 2000). Microarray analyses of arabidopsis genes during cold acclimation indicated that the expression of about 500 genes was either up- or down-regulated in response to low temperature (Fowler and Thomashow 2002; Vogel *et al.*, 2005). However, only about 15% of these genes were also responsive to CBF/DREB1 expression and could, therefore, be assigned to the CBF/DREB1 regulon. Therefore, although many of the genes that are most strongly induced in response to low temperature are regulated by CBF/DREB1, it is apparent that cold acclimation involves several low-temperature-responsive regulatory pathways.

Transgenic arabidopsis plants that constitutively over-express CBF1/DREB1B exhibited increased tolerance to freezing without negative side-effects on growth or development (Jaglo-Ottosen *et al.*, 1998). Expression of cold-responsive genes was shown to be activated in these plants at non-inducing temperatures (Jaglo *et al.*, 2001). Constitutive overexpression of CBF1/DREB1B in tomato plants also led to improved tolerance of chilling, drought and salt-stress, but these plants were stunted with reductions in fruit set and seed production (Hsieh *et al.*, 2002). Over-expression of CBF3/DREB1A in transgenic arabidopsis also leads to enhanced expression of target genes including *COR15a*, *RD29*, *KIN1*, *COR6.6*, and *COR47/RD17* (Liu *et al.*, 1998; Kasuga *et al.*, 1999; Maruyama *et al.*, 2004) under non-inducing conditions and these plants showed enhanced tolerance of freezing, drought and salt-stress. Constitutive expression of CBF3/DREB1A in transgenic rice plants resulted in increased tolerance to drought-, salt-, and cold-stress and these plants grew and developed normally (Oh *et al.*, 2005). Subsequently, the over-expression of CBF3/DREB1A was shown to improve the drought- and low-temperature-stress tolerance in tobacco, wheat and groundnut (Kasuga *et al.*, 2004; Pellegrineschi *et al.*, 2004; Bhatnagar-Mathur *et al.*, 2008), but the stress-inducible *RD29A* promoter was used to minimize the negative effects of CBF/DREB1 over-expression in these species.

Attempts to develop cotton plants that constitutively express CBF3/DREB1A under control of the CaMV 35S promoter in our laboratory failed. Regeneration proceeded normally through somatic embryogenesis, but the plantlets would not grow and most failed to develop roots (Y. Sun, J. Lee and R.D. Allen, unpublished data). Use of the stress-responsive *RD29A* promoter to drive stress-responsive CBF3/DREB1A expression allowed regeneration of plants that were able to thrive but were severely stunted and virtually all were sterile (J. Lee, Y. Sun and R.D. Allen, unpublished data). Development of transgenic cotton plants that contain a CBF3/DREB1A transgene under a different stress-responsive promoter that does not contain a CRT/DRE element has been carried out and these plants grow normally and are fertile. Initial characterization of the stress-tolerance characteristics of these plants indicates that they exhibit increased tolerance of water-deficit stress.

### *Protein Kinases*

Protein kinases represent another type of regulatory protein that has been used to improve stress tolerance in plants. Protein kinases initiate phosphorylation cascades that control downstream regulatory factors leading to altered stress-responsive gene expression and tolerance of abiotic stress. An advantage of engineering signaling factors is that they can control the signal output involved in different aspects of homeostasis or damage prevention under abiotic stress (Verslues *et al.*, 2006). One of these genes is the tobacco *NPK1* kinase and its arabidopsis ortholog *ANP1*, which activates a mitogen-activated protein kinase (MPK3 and MPK6) signaling cascade that leads to enhanced tolerance of multiple environmental stresses in tobacco and maize (Kovtun *et al.*, 2000; Shou *et al.*, 2004). *NPK1/ANP1* acts upstream of the oxidative-stress-response pathway and can induce expression of HSPs, APX, GST and other stress-responsive gene products. These proteins protect the photosynthetic machinery from damage during drought, thereby improving agronomic traits such as yield (Shou *et al.*, 2004). Other kinases interact with proteins directly to confer a stress response. For example, SOS2 (salt overly sensitive 2) directly regulates the $Na^+/H^+$ antiporter SOS1 (Shi *et al.*, 2000) that is known to be an important determinant of salt tolerance because of its role in ion homeostasis (Apse *et al.*, 1999; 2003; Gaxiola *et al.*, 1999). Although SOS2 is known to interact with the myristolyated calcium-binding protein, SOS3, in a calcium-dependent manner, SOS2 appears to limit plant salt tolerance (Guo *et al.*, 2004) and studies have shown that SOS2 is sufficient for activation of SOS1 and for increasing salt tolerance *in planta*. Recently developed cotton plants that express *AtANP1* and *At*SOS2 under control of the CaMV 35S promoter are now being tested for increased stress tolerance (Y. Sun, J. Lee, and R.D. Allen, unpublished data).

### *Ubiquitin and SUMO Ligases*

Post-translational modification of proteins via the attachment of a variety of small poly-peptides such as ubiquitin and small ubiquitin-like modifiers (SUMOs) is an important regulatory mechanism in eukaryotic cells, including those of plants (Melchior, 2000; Hay, 2001; Pickart, 2001; Vierstra, 2003; Gill, 2004; Kerscher *et al.*, 2006). Ubiquitin ligases, which catalyze the attachment of ubiquitin to target proteins and thereby regulate their stability and/or activity, are involved in a wide range of regulatory pathways including those of virtually all phytohormones. Several of these are involved in stress-signaling pathways; for example, transcriptional regulation of *CBF3/DREB1A* is modulated by post-translational modification of transcription factors while the stability of DREB2A is directly regulated by ubiquitination (see below). Furthermore, ring-finger proteins such as SDIR and XERICO affect ABA signaling and biosynthesis in arabidopsis (Ko *et al.*, 2006; Zhang *et al.*, 2007b), and a family of stress-associated proteins (SAPs) that contain A20- and AN1-like zinc-finger motifs are also involved in regulating stress responses (Mukhopadhyay *et al.*, 2004).

Conjugation of the SUMO peptide to a target motif of a protein substrate is known as sumoylation (Bernier-Villamor *et al.*, 2002; Melchior *et al.*, 2003; Schmidt and Müller, 2003; Johnson, 2004). Like ubiquitination, SUMO conjugation occurs in a series of biochemical steps mediated by E1-activating, E2-conjugating, and E3-ligating enzymes (Chosed *et al.*, 2006*)*. Whereas ubiquitin is primarily responsible for the degradation of cellular proteins, ligation of SUMO to target proteins can interfere with ubiquitination, alter protein–protein interactions and subcellular localization, and modify transcription-factor activity (Hochstrasser, 2000; 2001; Gill, 2003; Girdwood *et al.*, 2004; Johnson, 2004; Watts, 2004). Sumoylation has also been associated with the regulation of a wide range of cellular processes in eukaryotes including innate immunity, cell-cycle progression, heat adaptation, DNA repair, nucleocytoplasmic trafficking, subnuclear targeting, and transcriptional regulation (Mao *et al.*, 2000; Saitoh and Hinchey, 2000; Freiman and Tjian 2003; Bohren *et al.*, 2004; Dohmen 2004; Johnson 2004; Gill, 2005; Hay, 2005; Shuai and Liu, 2005; Zhao and Blobel 2005; Hietakangas *et al.*, 2006). In plants, levels of SUMO conjugates increase in response to a range of stresses, and sumoylation correlates with elevated expression of ABA- and stress-responsive genes (Kurepa *et al.*, 2003; Lois *et al.*, 2003; Miura *et al.*, 2005; 2007; Yoo *et al.*, 2006). An arabidopsis SUMO E3 ligase, SIZ1 regulates the expression of genes involved in controlling plant responses to phosphate starvation and cold stress (Miura *et al.,* 2005; 2007) and characterization of a *siz1* knockout mutant showed that loss of SIZ1 alters the expression of a set of genes in response to water deficit (Catala *et al.*, 2007). Recently, Miura *et al.* (2009) presented evidence that SIZ1 negatively regulates ABA signaling through sumoylation of ABI5. These authors demonstrate an epistatic genetic interaction between *SIZ1* and *ABI5*, and show that K391 in ABI5 is essential for SUMO1 conjugation. SUMO proteases encoded by the overly tolerant to salt 1 (*OTS1*) and *OTS2* genes, regulate salt-stress responses in arabidopsis. Double mutants are sensitive to salt and they accumulate higher levels of SUMO-conjugated proteins than wild-type plants under both normal and salt-stress conditions (Conti *et al.*, 2008). Over-expression of OTS1 in transgenic arabidopsis plants led to reduced levels of sumoylated proteins and increased salt tolerance compared to wild-type plants.

Ubiquitination and sumoylation can cooperate in the regulation of transcription factors involved in stress-responsive gene expression. For example, transcriptional regulation of members of the *CBF/DREB1* gene family, which are transiently induced by low temperature (Gilmour *et al.*, 1998; Liu *et al.*, 1998; Medina *et al.*, 1999) is controlled both at transcriptional and at post-transcriptional levels (Figure 1). Transcription of these genes is activated in response to low temperature by a constitutively expressed transcription factor, ICE1 (for inducer of CBF/DREB1 expression 1). ICE1 is a MYC-like basic helix-loop-helix transcription factor that binds to canonical MYC *cis*-elements (CANNTG) in the *CBF3/DREB1A* promoter. This interaction induces expression of CBF/DREB1, which leads to induction of the CBF/DREB1 regulon (Chinnusamy *et al.*, 2003). Negative transcriptional regulation of *CBF/DREB1* expression is mediated by MYB15, which binds to *CBF/DREB1* promoter elements and represses expression of *CBF/DREB1* genes and, thus, the CBF/DREB1 regulon (Agarwal *et al.,* 2006). While transcription of the *ICE1* gene is constitutive, the stability of the ICE1 protein is regulated by the RING-type E3 ubiquitin ligase HOS1 (Lee *et al.*, 2001), which ubiquitinates ICE1, targeting it to the 26S proteasome for degradation (Dong *et al.*, 2006). Since ubiquitination of ICE1 by HOS1 is induced by cold, HOS1 appears to be involved in the attenuation of plant responses to low temperatures. The activity of ICE1 is positively regulated via sumoylation by the SUMO ligase SIZ1 under cold conditions (Miura *et al.*, 2007). ICE1 sumoylation interferes with HOS1-dependent ubiquitination and suppresses expression of *MYB15*. Thus, under non-inducing conditions, transcription of *CBF/DREB1* genes is repressed by MYB15 and the accumulation of ICE1 is inhibited by HOS1-mediated ubiquitination. In response to stressful conditions, sumoylation of ICE1 by SIZ1 blocks its ubiquitination, leading to stabilization and/or activation. The accumulation of active ICE1 leads to the repression of *MYB15* and the transcriptional activation of *CBF/DREB1*.

Unlike the transcriptional regulation of the *CBF1/DREB1* gene family, regulation of DREB2A is primarily post-transcriptional. Over-expressed *DREB2A* in transgenic plants failed to confer an altered phenotype and had no apparent effect on the expression of stress-responsive genes. However, deletion of a small region in the central part of the *DREB2A*-coding sequence produced a constitutively active form called DREB2A-CA that, when expressed in arabidopsis, resulted in dwarfed growth and increased stress tolerance (Sakuma *et al.*, 2006). A recent search for protein factors that interact with the negative regulatory domain of DREB2A resulted in the identification of a unique RING-finger domain-containing E3 ubiquitin ligase named DREB2A interacting protein 1 (DRIP1) (Qin *et al.*, 2008). DRIP1 catalyzes the ubiquitination of DREB2A *in vitro* and mediates the stability of DREB2A *in planta*. Although E3 ligase genes such as HOS1 are expressed in response to stress and are thought to attenuate stress responses, DRIP1 is constitutively expressed and may be responsible for suppression of DREB2A expression under non-stressful conditions.

While the RING-finger E3 ubiquitin ligases HOS1 and DRIP1 negatively regulate plant-stress responses, other members of the RING-finger-domain protein family positively regulate stress responses. For example, over-expression of the RING-finger domain protein SDIR1 leads to increased drought-stress tolerance and enhanced expression of several ABA-responsive genes (Zhang *et al.,* 2007b) while over-expression of another RING-finger domain protein, XERICO, leads to increased ABA biosynthesis (Ko *et al.,* 2006). Although the cellular targets of these ubiquitin ligases have not been specifically identified, it is likely that they are transcription factors or other regulatory molecules that function to down-regulate stress responses.

A family of stress-responsive genes has been identified that encode proteins containing conserved A20-like and AN1-like zinc-finger motifs at their N- and C-terminal domains, respectively. Expression of the *OsiSAP1* gene from rice is induced in response to a variety of environmental stresses including cold, salt, drought, anoxia, wounding and heavy metals, and over-expression of this gene in transgenic tobacco plants conferred increased tolerance to abiotic stress (Mukhopadhyay *et al*., 2004). Similarly, overexpression of OsiSAP8 in both transgenic tobacco and rice conferred increased tolerance of salt, drought and cold stress, compared to unstressed transgenic plants, without a yield penalty (Kanneganti and Gupta, 2008). Vij and Tyagi (2006) identified 18 genes encoding putative SAP1-like proteins in the rice genome and 14 genes of this type were identified in arabidopsis. Like OsiSAP1, several of the rice *SAP* genes were found to be stress responsive (Vij and Tyagi, 2006) and analysis of public microarray data indicated that several of the *AtSAP* transcripts are strongly induced by ABA and a range of abiotic-stress treatments.

Transgenic arabidopsis plants that ectopically express the *AtSAP5* gene under control of the CaMV 35S promoter, as well as arabidopsis plants with antisense-suppressed *AtSAP5* expression and T-DNA knock-out mutants, were developed and characterized in our laboratory (Kang *et al*., 2011). The growth and development of these plants were indistinguishable from those of wild-type plants under normal, non-stressful conditions. However, when these plant were grown under chilling temperatures or exposed to water deficit, phenotypic differences became apparent. In general, AtSAP5 knockout and knock-down plants were more stress sensitive than wild-type plants under chilling and osmotic stress, whereas transgenic arabidopsis plants that over-express *AtSAP1* showed substantial increases in stress tolerance under water-deficit conditions.

Development of transgenic cotton plants that ectopically express AtSAP5 has been completed in our laboratory and several independent transgenic lines that express this transgene were regenerated (Hozain *et al*., 2012). When compared with wild-type plants, AtSAP5-expressing cotton plants showed increased survival under water deficit in greenhouse experiments (Figure 2). No differences were seen between AtSAP5 cotton plants and wild-type plants when they were grown under irrigated conditions in small-scale field trials. However, differences in stress tolerance were readily apparent in dry-land plots. When grown under water-deficit conditions, AtSAP5-expressing plants showed increased vegetative growth and reduced wilting and chlorosis relative to non-transformed plants. While bolls of wild-type cotton plants tended to open prematurely under these conditions, bolls of AtSAP5-expressing plants remained closed. Premature boll opening under drought stress results in production of immature, poor-quality cotton fibers, whereas fiber produced by AtSAP5 expressing plants was of higher quality. Thorough physiological evaluation and quantitative analysis of yield and fiber-quality parameters from these plants is now underway.

### *MicroRNAs*

MicroRNAs (miRNAs) and small interfering RNAs (siRNAs) represent an additional mode of post-transcriptional regulation in eukaryotic cells. These small non-coding RNAs can silence gene expression by targeting specific mRNAs for degradation or by repressing their translation (Bartel, 2004; Baulcombe, 2004; Jones-Rhoads *et al.*, 2006; Mallory and Vaucheret 2006). Although the function of miRNAs in developmental processes has been extensively studied (for recent reviews see Kidner and Martienssen, 2005; Mallory and Bouché, 2008), the roles of these molecules in the regulation of plant responses to abiotic stresses is now beginning to emerge (Sunkar *et al.*, 2007).

Jones-Rhoades and Bartel (2004) identified arabidopsis miRNAs that were predicted to target genes involved in abiotic-stress responses. For example, miR395, which is induced by sulfate starvation, targets transcripts for ATP sulfurylases and a sulfate transporter (Allen *et al.*, 2004; Jones-Rhoades and Bartel, 2004). Sunkar and Zhu (2004) identified several stress-responsive miRNAs, including miR393, which was strongly up-regulated by cold, dehydration, salinity, and ABA treatments. miR393 mediates cleavage of transcripts from several closely related F-box auxin-receptor genes, including transport inhibitor response 1 (*TIR1*), which, targets AUX/IAA proteins for ubiquitination (Vierstra, 2003). Thus, miR393-mediated inhibition of TIR1 down-regulates auxin signaling under abiotic-stress conditions. Accumulation of miR159 is induced by ABA via the seed-specific ABA-dependent transcription factor ABI3 (Reyes and Chua, 2007). miR159 targets transcripts for the MYB transcription factors MYB33 and MYB101 that are positive regulators of ABA signaling. Thus, miR159 may act to attenuate ABA responses in plants. Genes for two closely related Cu-Zn superoxide dismutase genes (*CSD1* and *CSD2*) are transcribed under normal growth conditions, but their mRNAs do not accumulate due to miR398-directed cleavage. miR398 is transcriptionally down-regulated in response to oxidative stress to allow increased accumulation and translation of *CSD1* and *CSD2* transcripts (Sunkar *et al.,* 2006), whereas induction of miR398 by sucrose-repressed expression of these mRNAs (Dugas and Bartel, 2008). Furthermore, plants that express a transgene for a mutant *CSD2* that is resistant to miR398-mediated cleavage accumulate higher levels of CSD2 transcripts and these plants showed improved tolerance to oxidative stress when compared to transgenic plants that express the miR398-susceptible CSD2 gene (Sunkar *et al.*, 2006). The recent identification of conserved microRNAs in cotton (Zhang *et al.*, 2007a) shows that opportunities exist to use this important post-transcriptional regulatory system in future efforts to optimize abiotic-stress tolerance in cotton.

## References

Agarwal PK *et al.* (2006) Role of DREB transcription factors in abiotic and biotic stress tolerance in plants. Plant Cell Reports 25 1263–1274.

Allen E *et al.* (2004) Evolution of microRNA genes by inverted duplication of target gene sequences in *Arabidopsis thaliana.* Nature Genetics 36 1282–1290.

Apse MP *et al.* (1999) Salt tolerance conferred by overexpression of a vacuolar $Na^{+}/H^{+}$ antiport in *Arabidopsis*. Science 285 1256–1258.

Apse MP *et al.* (2003) Vacuolar cation/$H^+$ exchange, ion homeostasis, and leaf development are altered in a T-DNA insertional mutant of *AtNHX1*, the Arabidopsis vacuolar $Na^+/H^+$ antiporter. The Plant Journal 36 229–239.

Baker SS *et al.* (1994) The 5'-region of *Arabidopsis thaliana cor15a* has *cis*-acting elements that confer cold-, drought- and ABA-regulated gene expression. Plant Molecular Biology 24 701–713.

Bartel DP (2004) MicroRNAs: genomics, biogenesis, mechanism, and function. Cell 116 281–297.

Baulcombe D (2004) RNA silencing in plants. Nature 431 356–363.

Bernier-Villamor V *et al.* (2002) Structural basis for E2-mediated SUMO conjugation revealed by a complex between ubiquitin-conjugating enzyme Ubc9 and RanGAP1. Cell 108 345–356.

Bhatnagar-Mathur P *et al.* (2008) Transgenic approaches for abiotic stress tolerance in plants: retrospect and prospects. Plant Cell Reports 27 411–424.

Bohren KM *et al.* (2004) A M55V polymorphism in a novel SUMO gene (SUMO-4) differentially activates heat shock transcription factors and is associated with susceptibility to type I diabetes mellitus. Journal of Biological Chemistry 279 27233–27238.

Boyer JS (1982) Plant productivity and environment. Science 218 443–448.

Burke EJ *et al.* (2006) Modeling the recent evolution of global drought and projections for the twenty-first century with the Hadley centre climate model. Journal of Hydrometeorology 7 1113–1125.

Catala R et al. (2007) The *Arabidopsis* E3 SUMO ligase SIZ1 regulates plant growth and drought responses. The Plant Cell 19 2952–2966.

Chinnusamy V *et al.* (2003) ICE1: a regulator of cold-induced transcriptome and freezing tolerance in Arabidopsis. Genes and Development 17 1043–1054.

Chosed R *et al.* (2006) Evolution of a signaling system that incorporates both redundancy and diversity: Arabidopsis SUMOylation. Biochemical Journal 398 521–529.

Conti L *et al.* (2008) Small ubiquitin-like modifier proteases OVERLY TOLERANT TO SALT1 and -2 regulate salt stress responses in Arabidopsis. The Plant Cell 20 2894–2908.

Dohmen RJ (2004) SUMO protein modification. Biochimica et Biophysica Acta 1695 113-131.

Dong CH *et al.* (2006) The negative regulator of plant cold responses, HOS1, is a RING E3 ligase that mediates the ubiquitination and degradation of ICE1. Proceedings of the National Academy of Sciences of the United States of America 103 8281–8286.

Dugas DV Bartel B (2008) Sucrose induction of Arabidopsis miR398 represses two Cu/Zn superoxide dismutases. Plant Molecular Biology 67 403–417.

FAO (Food, Agriculture Organization of the United Nations) (2004) FAO production yearbook. Rome: FAO.

Finkelstein RR *et al.* (2002) Abscisic acid signaling in seeds and seedlings. The Plant Cell 14 (suppl.) S15–S45.

Fowler S Thomashow MF (2002) Arabidopsis transcriptome profiling indicates that multiple regulatory pathways are activated during cold acclimation in addition to the CBF cold response pathway. The Plant Cell 14 1675–1690.

Freiman RN Tjian R (2003) Regulating the regulators: lysine modifications make their mark. Cell 112 11–17.

Gaxiola RA *et al.* (1999) The *Arabidopsis thaliana* proton transporters, AtNhx1 and Avp1, can function in cation detoxification in yeast. Proceedings of the National Academy of Sciences of the United States of America 96 1480–1485.

Gill G (2003) Post-translational modification by the small ubiquitin related modifier SUMO has big effects on transcription factor activity. Current Opinion in Genetics and Development 13 108–113.

Gill G (2004) SUMO and ubiquitin in the nucleus: Different functions, similar mechanisms? Genes and Development 18 2046–2059.

Gill G (2005) Something about SUMO inhibits transcription. Current Opinion in Genetics and Development 15 536–541.

Gilmour SJ *et al.* (1998) Low temperature regulation of the Arabidopsis CBF family of AP2 transcriptional activators as an early step in cold-induced COR gene expression. The Plant Journal 16 433–443.

Gilmour SJ *et al.* (2000) Overexpression of Arabidopsis CBF3 transcriptional activator mimics multiple biochemical changes associated with cold acclimation. Plant Physiology 124 1854–1865.

Girdwood DW *et al.* (2004) SUMO and transcriptional regulation. Seminars in Cell and Developmental Biology 15 201–210.

Guo Y *et al.* (2004) Transgenic evaluation of activated mutant alleles of *SOS2* reveals a critical requirement for its kinase activity and C-terminal regulatory domain for salt tolerance in *Arabidopsis thaliana*. The Plant Cell 16 435–449.

Hay RT (2001) Protein modification by SUMO. Trends in Biochemical Sciences 26:332–333.

Hay RT (2005) SUMO: a history of modification. Molecular Cell 18 1–12.

Hietakangas V *et al.* (2006) PDSM, a motif for phosphorylation-dependent SUMO modification. Proceedings of the National Academy of Sciences of the United States of America 103 45–50.

Himmelbach A *et al.* (2003) Relay and control of abscisic acid signaling. Current Opinion in Plant Biology 6 470–479.

Hochstrasser M (2000) Evolution and function of ubiquitin-like protein conjugation systems. Nature Cell Biology 2 E153–E157.

Hochstrasser M (2001) SP-RING for SUMO: New functions bloom for a ubiquitin-like protein. Cell 107 5–8.

Hozain M *et al.* (2012) Over-expressing AtSAP5 in cotton up-regulates putative stress-responsive genes and improves the tolerance to rapidly developing water deficit and moderate heat stress. Journal of Plant Physiology 169 1261–1270.

Hsieh TH *et al.* (2002) Tomato plants ectopically expressing Arabidopsis CBF1 show enhanced resistance to water deficit stress. Plant Physiology 130 618–626.

Jaglo KR *et al.* (2001) Components of the Arabidopsis C-repeat/ dehydration-responsive element binding factor cold response pathway are conserved in *Brassica napus* and other plant species. Plant Physiology 127 910–917.

Jaglo-Ottosen KR *et al.* (1998) Arabidopsis CBF1 overexpression induces cor genes and enhances freezing tolerance. Science 280 104–106.

Johnson ES (2004) Protein modification by SUMO. Annu Rev Biochem 73 355–382.

Jones-Rhoades MW Bartel DP (2004) Computational identification of plant microRNAs and their targets, including a stress induced miRNA. Molecular Cell 14 787–799.

Jones-Rhoades MW *et al.* (2006) MicroRNAS and their regulatory roles in plants. Annual Review of Plant Biology 57 19–53.

Kagaya Y *et al.* (2002) Abscisic acid induced transcription is mediated by phosphorylation of an abscisic acid response element binding factor, TRAB1. The Plant Cell 14 3177–3189.

Kang J-Y *et al.* (2002) Arabidopsis basic leucine zipper proteins that mediate stress-responsive abscisic acid signaling. The Plant Cell 14 343–357.

Kang M *et al.* (2011) Arabidopsis SAP5 functions as a positive regulator of stress responses and exhibits E3 ubiquitin ligase activity. Plant Molecular Biology 75 451–466.

Kanneganti V Gupta AK (2008) Overexpression of OsiSAP8, a member of stress associated protein (SAP) gene family of rice confers tolerance to salt, drought and cold stress in transgenic tobacco and rice. Plant Molecular Biology 66 445–462.

Kasuga M *et al.* (1999) Improving plant drought, salt, and freezing tolerance by gene transfer of a single stress inducible transcription factor. Nature Biotechnology 17 287–291.

Kasuga M *et al.* (2004) A combination of the *Arabidopsis* DREB1A gene and stress inducible rd29A promoter improved drought- and low-temperature stress tolerance in tobacco by gene transfer. Plant Cell Physiology 45 346–350.

Kerscher O *et al.* (2006) Modification of proteins by ubiquitin and ubiquitin-like proteins. Annual Review of Cell and Developmental Biology 22 159–180.

Kidner CA Martienssen RA (2005) The developmental role of micro-RNA in plants. Current Opinion in Plant Biology 8 38–44.

Ko JH *et al.* (2006) Upregulation of an Arabidopsis RING-H2 gene, XERICO, confers drought tolerance through increased abscisic acid biosynthesis. The Plant Journal 47 343–355.

Kornyeyev D *et al.* (2001) Enhanced photochemical light utilization and decreased chilling-induced photoinhibition in cotton overexpressing genes encoding chloroplast-targeted antioxidant enzymes. Physiologia Plantarum 113 323–331.

Kovtun Y *et al.* (2000) Functional analysis of oxidative stress-activated mitogen-activated protein kinase cascade in plants. Proceedings of the National Academy of Sciences of the United States of America 97 2940–2945.

Kuhn JM Schroeder JI (2003) Impacts of altered RNA metabolism on abscisic acid signaling. Current Opinion in Plant Biology 6 463–469.

Kurepa J *et al.* (2003) The small ubiquitin-like modifier (SUMO) protein modification system in Arabidopsis: accumulation of SUMO1 and -2 conjugates is increased by stress. Journal of Biological Chemistry 278 6862–6872.

Lee H *et al.* (2001) The Arabidopsis HOS1 gene negatively regulates cold signal transduction and encodes a RING finger protein that displays cold-regulated nucleo-cytoplasmic partitioning. Genes and Development 15 912–924.

Liu Q *et al.* (1998) Two transcription factors, DREB1 and DREB2, with an EREBP/AP2 DNA binding domain separate two cellular signal transduction pathways in drought- and low temperature-responsive gene expression, respectively, in Arabidopsis. The Plant Cell 10 1391–1406.

Lois LM *et al.* (2003) Small ubiquitin-like modifier modulates abscisic acid signaling in Arabidopsis. The Plant Cell 15 1347–1359.

Mallory AC Bouché N (2008) MicroRNA-directed regulation: to cleave or not to cleave. Trends in Plant Science 13 359–367.

Mallory AC Vaucheret H (2006) Functions of microRNAs and related small RNAs in plants. Nature Genetics 38 S31–S36.

Mao Y *et al.* (2000) SUMO-1 conjugation to human DNA topoisomerase II isozymes. Journal of Biological Chemistry 275 26066–26073.

Maruyama K *et al.* (2004). Identification of cold-inducible downstream genes of the Arabidopsis DREB1A/CBF3 transcriptional factor using two microarray systems. The Plant Journal 38 982–993.

Medina J *et al.* (1999) The Arabidopsis *CBF* gene family is composed of three genes encoding AP2 domain-containing proteins whose expression is regulated by low temperature but not by abscisic acid or dehydration. Plant Physiology 119 463–469.

Melchior F (2000) SUMO–nonclassical ubiquitin. Annual Review of Cell and Developmental Biology 16 591–626.

Melchior F *et al.* (2003) SUMO: ligases, isopeptidases and nuclear pores. Trends in Biochemical Science 28 612–618.

Miura K *et al.* (2005) The Arabidopsis SUMO E3 ligase SIZ1 controls phosphate deficiency responses. Proceedings of the National Academdy of Sciences of the United States of America 102 7760–7765.

Miura K *et al.* (2007) SIZ1-mediated sumoylation of ICE1 controls CBF3/DREB1A expression and freezing tolerance in Arabidopsis. The Plant Cell 19 1403–1414.

Miura K *et al.* (2009) Sumoylation of ABI5 by the *Arabidopsis* SUMO E3 ligase SIZ1 negatively regulates abscisic acid signaling. Proceedings of the National Academy of Sciences of the United States of America 106 5418–5423.

Mukhopadhyay A *et al.* (2004) Overexpression of a zinc-finger protein gene form rice onfers tolerance to cold, dehydration, and salt stress in transgenic tobacco. Proceedings of the National Academdy of Sciences of the United States of America 101 6309–6314.

Narusaka Y *et al.* (2003) Interaction between two *cis*-acting elements, ABRE and DRE, in ABA-dependent expression of Arabidopsis *rd29A* gene in response to dehydration and high-salinity stresses. The Plant Journal 34 137–148.

Oh SJ *et al.* (2005) Arabidopsis CBF3/DREB1A and ABF3 in transgenic rice increased tolerance to abiotic stress without stunting growth. Plant Physiology 138 341–351.

Park MY *et al.* (2005) Nuclear processing and export of microRNAs in *Arabidopsis.* Proceedings of the National Academdy of Sciences of the United States of America 102 3691–3696.

Payton P *et al.* (2001) Protecting cotton photosynthesis during moderate chilling at high light intensity by increasing chloroplastic antioxidant enzyme activity. Journal of Experimental Botany 52 2345–2354.

Pellegrineschi A *et al.* (2004) Stress-induced expression in wheat of the *Arabidopsis thaliana* DREB1A gene delays water stress symptoms under greenhouse conditions. Genome 47 493–500.

Pickart CM (2001) Mechanisms underlying ubiquitination. Annual Review of Biochemistry 70 503–533.

Qin F *et al.* (2008) Arabidopsis DREB2A-interacting proteins function as RING E3 ligases and negatively regulate plant drought stress-responsive gene expression. The Plant Cell 20 1693–1707.

Ragauskas AJ *et al.* (2006) The path forward for biofuels and biomaterials. Science 311 484–489.

Ramachandra-Reddy A *et al.* (2004) Drought-induced responses of photosynthesis and antioxidant metabolism in higher plants. Journal of Plant Physiology 161 1189–1202.

Reyes JL Chua NH (2007) ABA induction of miR159 controls transcript levels of two MYB factors during Arabidopsis seed germination. The Plant Journal 49 592–606.

Roxas, VP *et al.* (2000) Stress tolerance in transgenic tobacco seedlings that overexpress glutathione S-transferase/glutathione peroxidase. Plant and Cell Physiology 41 1229–1234.

Saitoh H Hinchey J (2000) Functional heterogeneity of small ubiquitin-related protein modifiers SUMO-1 *versus* SUMO-2/3. Journal of Biological Chemistry 275 6252–6258.

Sakuma Y *et al.* (2006) Functional analysis of an *Arabidopsis* transcription factor, DREB2A, involved in drought responsive gene expression. The Plant Cell 18 1292–1309.

Schmidt D Müller S (2003) PIAS/SUMO: new partners in transcriptional regulation. Cellular and Molecular Life Sciences 60 2561–2574.

Shen Q Ho TH (1995) Functional dissection of an abscisic acid (ABA)-inducible gene reveals two independent ABA-responsive complexes each containing a G-box and a novel cis-acting element. The Plant Cell 7 295–307.

Shi H *et al.* (2000) The *Arabidopsis thaliana* salt tolerance gene *SOS1* encodes a putative $Na^+/H^+$ antiporter. Proceedings of the National Academy of Sciences of the United States of America 97 6896–6901.

Shinozaki K *et al.* (2003) Regulatory network of gene expression in the drought and cold stress responses. Current Opinion in Plant Biology 6 410–417.

Shou H *et al.* (2004) Expression of the *Nicotiana* protein kinase (NPK1) enhanced drought tolerance in transgenic maize. Journal of Experimental Botany 55 1013–1019.

Shuai K Liu B (2005) Regulation of gene-activation pathways by PIAS proteins in the immune system. Nature Reviews Immunology 5 593–560.

Stockinger EJ *et al.* (1997) *Arabidopsis thaliana CBF1* encodes an AP2 domain-containing transcription activator that binds to the C-repeat/DRE, a *cis*-acting DNA regulatory element that stimulates transcription in response to low temperature and water deficit. Proceedings of the National Academy of Sciences of the United States of America 94 1035–1040.

Sunkar R Zhu JK (2004) Novel and stress-regulated microRNAs and other small RNAs from *Arabidopsis*. The Plant Cell 16 2001–2019.

Sunkar R *et al.* (2006) Posttranscriptional induction of two Cu/Zn superoxide dismutase genes in *Arabidopsis* is mediated by downregulation of miR398 and important for oxidative stress tolerance. The Plant Cell 18 2051–2065.

Sunkar R *et al.* (2007) Small RNAs as big players in plant abiotic stress responses and nutrient deprivation. Trends in Plant Science 12 301–309.

Thomashow MF (1998) Role of cold responsive genes in plant freezing tolerance. Plant Physiology 118 1–8.

Umezawa T *et al.* (2006) Engineering drought tolerance in plants: discovering and tailoring genes to unlock the future. Current Opinion in Biotechnology 17 113–122.

Vanjildorj E *et al.* (2005) Overexpression of *Arabidopsis* ABF3 gene enhances tolerance to drought and cold in transgenic lettuce (*Lactuca sativa*). Plant Cell, Tissue and Organ Culture 83 41–50.

Verslues PE *et al.* (2006) Methods and concepts in quantifying resistance to drought, salt and freezing, abiotic stresses that affect plant water status. The Plant Journal 45 523–539.

Vierstra RD (2003) The ubiquitin/26S proteasome pathway, the complex last chapter in the life of many plant proteins. Trends in Plant Science 8 135–142.

Vij S Tyagi AK (2006) Genome-wide analysis of the stress associated protein (SAP) gene family containing A20/AN1 zinc-finger(s) in rice and their phylogenetic relationship with *Arabidopsis.* Molecular Genetics and Genomics 276 565–575.

Vogel J *et al.* (2005) Roles of the CBF2 and ZAT12 transcription factors in configuring the low temperature transcriptome of Arabidopsis. The Plant Journal 41 195–211.

Wang W *et al.* (2003) Plant responses to drought, salinity and extreme temperatures: towards genetic engineering for stress tolerance. Planta 218 1–14.

Watts FZ (2004) SUMO modification of proteins other than transcription factors. Seminars in Cell and Developmental Biology 15 211–220.

Wilkins TA *et al.* (2000) Cotton biotechnology. Critical Reviews in Plant Science 19:51-550.

Yamaguchi-Shinozaki K *et al.* (1994) Function and regulation of genes that are induced by dehydration stress in *Arabidopsis thaliana*. Japan International Research Center for Agricultural Sciences Journal 1 69–79.

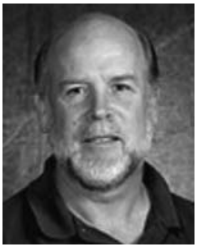
Yoo CY *et al*. (2006) SIZ1 small ubiquitin-like modifier E3 ligase facilitates basal thermotolerance in *Arabidopsis* independent of salicylic acid. Plant Physiology 142 1548–1558.

Zhang JZ *et al.* (2004) From laboratory to field. Using information from *Arabidopsis* to engineer salt, cold, and drought tolerance in crops. Plant Physiology 135 615–621.

Zhang B *et al.* (2007a) Identification of cotton microRNAs and their targets. Gene 397 26–37.

Zhang Y *et al.* (2007b) SDIR1 is a RING finger E3 ligase that positively regulates stress-responsive abscisic acid signaling in *Arabidopsis.* The Plant Cell 19 1912–1929.

Zhao X Blobel G (2005) A SUMO ligase is part of a nuclear multiprotein complex that affects DNA repair and chromosomal organization. Proceedings of the National Academy of Sciences of the United States of America 102 4777–4782.



**RANDY ALLEN**, professor of biochemistry and molecular biology at Oklahoma State University, moved his research program from Texas Tech University to assume the directorship of the Institute for Agricultural Biosciences located adjacent to the Samuel Roberts Noble Foundation in Ardmore, Oklahoma.He earned a PhD at Texas A&M University and worked as a postdoctoral associate at Washington University in St. Louis. His research interests include the analysis of the regulatory mechanisms that control the expression of genes in response to environmental signals, especially those involved in stress tolerance. Recent research in Dr. Allen's laboratory has focused on functional analysis of transcription factors, ubiquitin ligases and other agents involved in controlling cellular signaling pathways that mediate plant development and the acclimation of plants to harsh environments.

# *Agricultural Adaptations to Water Needs*

Q&A[1]


Moderator: Rick Bennett
*University of Arkansas*
*Fayetteville, Arkansas*


Dave Warner: Hank, what is the efficiency of phosphorus recovery?

Hank Venema: When burning cattails in a conventional furnace it's not optimized at all for phosphorus recovery. Nevertheless, at first try, we recovered 90%, well actually 89%, of the phosphorus in the ash. The only gaseous form of phosphorus is phosgene, and we are not producing that. So, the phosphorus has nowhere else to go.

Venema: I have a question for Wes. What yields are obtained from perennial crops?

Wes Jackson: Perennials are low yielding, but, for instance, with Kernza™ we get an increase of about 100 pounds per acre per selection cycle. There's more total biomass in perennial wheatgrass than there is in annual wheat, but the harvest index is much smaller in the former; it's not around 0.5 as in wheat. So, breeding is mostly a matter of changing the harvest index, of breeding to alter allocation. The perennial captures more sunlight as it has a longer growing season. An important paper was published by David Van Tassel and colleagues on why our ancestors did not develop perennial grains. They point out that annuals tend to self-fertilize and, by selfing, they inbreed and so the genetic load does not build up. Herbaceous perennials tend to outcross and, therefore, have a great deal of heterozygosity and a rather high level of genetic load. The good thing about the

[1]The audiorecording, from which this written record was prepared, was of poor quality, rendering it impossible to accurately represent the dialogue in many places. Every effort has been made to provide a faithful transcription.

annual is that a desirable trait, like shatter-resistance, can be obtained relatively quickly. However, inbreeding results in only about half of the seeds being filled. The other seeds contain aborted embryos, essentially getting rid of the genetic load. The way we look at it is that, yea though we go through the valley of the shadow of death, we fear no evil, for the evolutionary force is with us, actually increasing the number of viable embryos. Now, imagine our ancestors, at the eastern end of the Mediterranean with annuals. We can do what they could not do, partly because of our knowledge of genetics, our computational power and the use of molecular markers. We argue that if you want high seed yields in the future, they will be achieved with perennials. Annuals have too many limits placed on them.

Venema: I appreciate your latter point. But if life-cycle sustainability, reduced greenhouse-gas emissions, and so forth, are part of our major objective here, why not focus perennials on fiber and fuel production where they're already extremely efficient and where we can displace very typically unsustainable value chains that have a heavy atmospheric load?

Jackson: First, a chief concern is soil erosion in annuals. According to a paper, of which Chris Field was an author, from 1700 to 2000 we have had three times the total agricultural acreage of the US—on a global basis—go out of production. We are losing our soils. The second part is to deal with the question of biofuels; a massive biofuels program won't do what a very modest conservation program will do. For instance, the average American consumes the equivalent of 26 gallons of gasoline a year in food calories. So let's say that we don't eat for a year and we turn all of our food into biofuels. That's 2 gallons a month per person. Now, let's say that we take all the wheat straw, peanut shells, and corn stalks, and so on, and turn them into biofuels—maybe another 2 gallons a month per person, depending on how you calculate it. Stop all exports—another 1½ to 2 gallons. So, at the most, 6 gallons a month per person. Our view is that, with a modest conservation program, we won't have to turn to our soils to produce biofuels.

Venema: A reflection on the afternoon with respect to sustainability. The hand-out package contains a white paper from NABC on climate change. An important observation is that we tend to look for single-issue solutions and, I know in my jurisdiction, historically we have too much water in the spring and there is overdrainage, and, of course, that vulnerability has been revealed many times because occasionally we have severe drought in our region as well. The likely impact of climate change will be more variability—both increased flood episodes and increased drought episodes. So, what we are really looking for is resilience to variability for sustainability rather than single-issue adaptation. I just want to throw that out there to get people thinking. The only robust prediction is increased variability.

Jackson: I think that it will come back to a natural ecosystem like the prairie. During the dust-bowl years, the wheat plants died in Kansas; the prairie came back. If prairie bottoms get flooded, they come back. If you flood soybean or corn, you kill it. So, if you are talking about resilience and sustainability, there must be a pretty good reason why, when nature's ecosystems regenerate, they favor the perennial.

Anna McClung (USDA-ARS, Stuttgart): Dr. Warner, has there been an attempt to define megaenvironments so to speak, or specific environments that one could develop specific traits for, and, if that's the case, have you looked at how those environments might be altered in response to climate change over the next few years? The package of traits today for a variety for a specific area or region may have to evolve over time to comprise different traits.

Dave Warner: The short answer is "yes." Our environmental modeling group collaborates with several NGO and academic agencies who are projecting where we need to be in 10 or 15 years. The rate of climate change is usually slower than how quickly we can adapt our breeding technologies. We are monitoring climate changes.

McClung: Do you want to comment on trends that you have identified?

Warner: This is a little bit outside my expertise. One of our breeders spoke to the Crop Science Society last fall about that, for which he produced a couple of slides that I wish I had brought with me. They showed shifts in the environments in the western part and center of the corn belt with higher temperatures moving north possibly expanding the corn belt. These are 20-year trends and beyond.

Andy Pereira (University of Arkansas, Fayetteville): Dr. Jackson, in the domestication of plants as crops, certain traits were selected for such as non-shattering pods, time to flowering and increased seed size. For perennials, a main objective is ensuring survival from year to year. How does this relate to grain yield?

Jackson: There are perennials that do have large seeds—trees for example—and have high yields and they have the same amount of sunlight striking them per square meter. The herbaceous perennials have not *had* to have large seeds because they have perennial tissue below, but it does not mean that they cannot be bred to have large seeds by changing the harvest index. Also, overall, photosynthetic capture is longer than for annuals. Therefore, more photosynthate is available for reallocation. The r and K[2] selection strategies do not apply absolutely in plants, if that is your concern. If you select for high seed yield—which is what we do—by increasing seed size and seed number and your total photosynthetic capture is longer, then the perennial has even greater potential for higher yield than the annual. The annual has a shorter photosynthetic capture period. For instance, our winter-hardy perennial sorghum has a full canopy three weeks before annual sorghum germinates.

---

[2]http://en.wikipedia.org/wiki/R/K_selection_theory.

Kelly Foley (Oregon State University, Corvallis): What's being done to help producers make the shift from annual to perennial crops?

Jackson: How are farmers responding to the shift from annual crops to perennials? We don't have any seed ready, so there's no response. But, you can imagine who won't be interested: the seed houses and the fertilizer people, especially if you have a legume in your system you will purchase less nitrogen. Perennials provide species diversity and chemical diversity, so it takes a tremendous effort on the part of an insect or a pathogen to produce an epidemic. So the pesticide people won't be much interested. The reward goes to the farmer and the landscape rather than to the suppliers of inputs, where most of the money is made in agriculture. Farmers don't have any problem with the concept. They are at us almost every day to give them seed.

Foley: Do you anticipate a backlash from a major switch from annuals to perennials?

Jackson: About like the switch from the Ptolemaic system to the Copernican system. Yeah, there will be a backlash because there's a lot on the line. You think about how humanity has 10,000 years of annuals that have been feeding us—and soil erosion has gone along with that—but we are in tune with the patterns that come with that kind of agriculture. However, we need to recognize that the plowshare is destroying the options of future generations. This is a psychological shift that comes from nature being subdued or ignored to nature being the teacher, with ecology overriding agronomy. Think how exciting that is.

Douglas Cattani (University of Manitoba, Winnipeg): Although I don't think there will be a mass acceptance, I think that a small group currently within the seed-production industry would be amenable to fostering adaption to farming perennials.

Ralph Hardy (National Agricultural Biotechnology Council, Ithaca): A broad-canopy question. In the area of societal benefits, in some cases the producer will see benefit. It may be with an organic crop for which a premium price may be charged. How do you see the societal benefits related to water having value-added for the producer to induce her/him to adopt them?

Venema: Can you give specific examples of potential benefits?

Hardy: Like less phosphate pollution, from which a farmer won't benefit directly, but society will.

Venema: It's funny because I have gone through a similar evolution in thinking. I started in my position about six years ago, and the narrative at the time was about payments to farmers for ecosystem services, which was appealing to growers in Canada, that they would be compensated for certain practices—or in some cases, certain non-practices—that had associated public benefit. I think that that's valid. Public benefits from some agricultural practices are significant, but are not felt on-farm, so there should be a compensation mechanism. What that means is, from sustainable development first principles, you subsidize "goods" not "bads." A public subsidy is justified if there's a positive public externality. What we shouldn't be doing is subsidizing agricultural practices when there is definitely a negative public externality. That's illogical. Now, all that said, if we get negative subsidies out of the system that might be enough to start encouraging positive public externalities, but I'm not sure that will be the case. I am not convinced that there are enough resources to provide subsidies for public benefits even if we get the negative subsidies out of the system.

Bill McCutchen (Texas A&M University, College Station): Wes Jackson and others are working on 200-year sustainability projects and I'm wondering if Dave Warner and Randy Allan could talk about feeding the world of 9 billion people here in the next 15 to 20 years. How can industry and academia work more closely together to help make that happen? I know we are going to use annuals for a while—I accept that fact—but how can the technology that is being developed at Oklahoma State, at UC Davis or at Cornell be more efficiently utilized by companies such as Pioneer and Monsanto? There's a large gap there. Many technologies being developed in academia are sitting on the shelf; they can't be transferred because of regulatory hurdles. A lot of things are happening on the major row crops, but not on the specialty crops.

Warner: At Pioneer, we work closely with many academic organizations and NGOs on a lot of this technology and we license many genes from various sources, including academic sources. The biggest challenge for academics in small organizations with transgenes in particular is that the USDA requires extensive multi-year testing to document safety. It can take millions of dollars to usher a new product to the market place. That's why a small organization may license a new technology to a company like ours to take it to market.

Venema: The fraction of the US domestic corn crop eaten as food is about 2%. From the perspective of world food security, the elephant in the room is the enormous amount of cereal used for livestock production. It's a difficult question. I'm an omnivore like most of us, but that's the reality. A solution is to go from cereal production directly to food consumption rather than through the inefficiency of livestock production.

Hardy: It is my recollection that China now eats twice as much meat as the United States. This issue has to be considered on a global scale.

Audience member: Are we approaching a point where we will legislate what people can and can't eat?

Jackson: It's the language of the industrial hero who is forever asking how we are going to feed 9 billion without asking the next question: then what? 12 billion? 15? Whatever?

We do have a population problem, but what is not factored in often enough, is dealing with the question: what do people, deer, cars and houses and deep freezers and pop-up toasters have in common? They are all members of populations and they all occupy space and they are all dissipating structures. So, yes, we have a population problem. There are too many people, too many cars, too many houses, too many pop-up toasters, and so on. The more that we accumulate, the more regulations we will need or the planet will regulate us. It will regulate our behavior. It will regulate our numbers, and so on. We all know that. This is one reason people are starting to look more at the structure of the human brain as a product of the Paleolithic past. Is the neuro-network hard-wired? How much of it is amenable to learning new things? We need to think about what stands in our way of learning and changing. Kittens that are blindfolded at birth and kept that way for 6 weeks never learn to see; the neuro-network doesn't develop. So, in a certain sense, we are all blind kittens as a result of our experiences; it doesn't seem that our education in primary schools, high schools, and universities prepares us for overcoming our cultural and regional history. Until we come to terms with that neuro-network and the knowledge that this is part of what it takes to be a primate then we are going to get where we are going. The advertising industry knows one big thing: we are animals. And they also know that the rest of us don't know that. They are on to it, though. Consequently, we go merrily along depleting our resources and breeding. We must move into new territory in the sciences that is uncomfortable to us.

Veneman: I have a somewhat similar answer. In Canada, we have significantly higher fuel taxes than in the United States, and in Europe there are far higher fuel taxes yet than in Canada. And that is because they are attempting to internalize the public cost, since many externalities result from the use of fossil fuels. I am being slightly facetious, but only slightly: a tax on meat would, to some degree, provide invisible-hand moderation and might free up cereals for human consumption.

Rick Bennett: Josef Stalin said, "It's better to kill 1000 people in one day than 1 a day for 1000 days." That may have worked for him as a dictator, but it didn't work for him in Uzbekistan when he directed that the Aral Sea be exploited to grow irrigated cotton, which illustrates what we have been talking about: it's going to take societal and broad institutional changes and adoption of sustainability practices. It's going to take good science, the kind in progress on transgenic crops. And it's going to take good, solid policy.

## DEVELOPMENTS IN WATER MANAGEMENT AND POLICY

# *Reaching the Potential of Water-Quality Trading*

Richard H. Moore
*The Ohio State University*
*Wooster, Ohio*

moore.11@osu.edu

In 2003 the US Environmental Protection Agency (USEPA) created a Water Quality Trading Policy consistent with the Clean Water Act of 1972. Building on the successes of the National Pollutant Discharge Elimination System (NPDES) permit program to address point-source discharges and the Total Maximum Daily Load (TMDL) program, which established watershed pollution loads, water-quality trading was created as a new rule to address the approximately 40% of the rivers, 45% of the streams and 50% of the lakes that had still not met their designated uses. Section 303(d) of the Clean Water Act mandates that states assess their waters every two years. Each state creates a list of waters that are impaired. TMDLs are then written for those impaired water bodies, allocating allowable pollutant loads from the various sources in the impaired watershed. Part of this is to set a load limit for point sources such as wastewater treatment plants (WWTPs) and industry. TMDLs were referenced in Section 303 of the 1972 Clean Water Act.

Water-quality trading is defined as (USEPA, 2003):

> *…an approach that offers greater efficiency in achieving water-quality goals on a watershed basis. It allows one source to meet its regulatory obligations by using pollutant reductions created by another source that has lower pollution control costs.*

Presently there are 24 active water-quality-trading programs in the United States (Willamette Partnership, 2012) although, as noted by Mariola (2009), the actual figure may be somewhat less and even fewer are truly functioning. Currently, nine states have rules defining the local interpretation of the rules through statewide regulatory authority for trading via statute, regulation, policy, or guidance. This article reflects on the successes of one program, the Alpine Cheese Phosphorus Nutrient Trading Plan, and the reasons why it was successful. It is one of the few programs in the country to have fully met the requirements of an NPDES permit. As a result, this permit was renewed in 2012 for a second five-year term. Additionally, the local popularity of the program led to the creation of a 21-county Muskingum Joint Board of Soil and Water Conservation District whose supervisors proposed a water-quality-trading plan that will cover nearly a quarter of Ohio. The reasons for the successes of the Alpine Plan can be categorized into the following sections:

- A clear regulatory framework,
- Economic framework,
- Organization of the program, and
- Ecological significance.

## Background

The State of Ohio has the following water-quality-trading programs:

- The Alpine Cheese Nutrient Trading Plan,
- The Walnut Creek Water Quality Trading Plan,
- The Great Miami River Water Quality Credit Trading Program, and
- The Ohio Basin Trading Plan.

Ohio has been a national leader in experimenting with approaches to water-quality trading. Both the Alpine Cheese Phosphorus Nutrient Trading Plan and the Great Miami River Water Quality Trading Plan were the first programs approved by Ohio EPA (OEPA) before the Ohio water-quality-trading rules were formalized in 2007. Both plans were developed between 2005 and 2006 and are grandfathered in the Ohio rules. The Alpine Plan has a 4:1 trading ratio whereas the Miami Plan has a 2:1 ratio referring to the credits ratio between buyer and seller. Usually the buyer is a point source and the sellers are farmers. In both cases, the ratio favors improving the watershed water quality more than if the point source met the NPDES permit requirements through a complete facility upgrade. The Miami Plan ratio was based on the idea that there would be proactive trades before formal regulations were imposed by OEPA on the Dayton area wastewater-treatment plants. The Alpine Nutrient Trading Plan had a more conservative trading ratio and was conducted in an area where a TMDL was in place, so the cheese factory had a load limit. Load is calculated by multiplying concentration times flow. So when there is a TMDL in place, all point-source loads are documented and then a point source can increase its outflow only if it decreases its concentration of the pollutant or *vice versa*. Of course, the higher the ratio, the higher the cost to the point source. The Ohio rules decided on a midpoint of 3:1, but it is possible to request a lower ratio for pre-TMDL watersheds.

The Alpine and the Miami Plans also differ by the broker type and the credit-market instrument. The Alpine Plan is administered by a county Soil and Water Conservation District, which contracts individually with farmers in order to fill the necessary credits for the Alpine Cheese Company's NPDES five-year permit, which officially started January 1, 2007. The Miami Plan is administered by the Miami Watershed Conservancy District, which conducts a reverse auction (lowest price wins) with bids coming from the Soil and

Water Conservation Districts (SWCDs) in the 15 counties in the district. The county SWCDs prepare bids with their local farmers. The lowest bids are then selected by the Miami Watershed Conservancy District. This is in contrast to the approach of the Alpine program, which placed the county SWCD as the broker of the program. The success of the Alpine Cheese case led to the formation of a 21-county Muskingum River Watershed Joint Board of Soil and Water Conservation Districts on June 17, 2010. This group, approved by the Ohio Soil and Water Conservation Commission, has a water-quality-trading program pending with the OEPA. Approval is expected in late 2012. Like the Alpine case, this program favors trades at a more local level, while not ruling out trades across counties or states.

It is important to realize that while Ohio is a leader in the diversity of water-quality-trading programs, many other possibilities can be developed to create an appropriate program for any given set of environmental or cultural situations. Selman *et al.* (2009) has listed several market structures: bilateral negotiations, sole-source offsets, brokered trades, auction platforms, and exchange markets. It is also possible to use multiple exchange markets in the same program. According to a new manual by the Willamette Partnership (2012), there is the following breakdown of the 25 active programs using four types of market structure: 67% use bilateral trades, 46% use sole-source offsets, 21% use an auction platform, and 17% use an exchange market.

Finally, the Ohio Basin Plan, developed by the Electric Power Research Institute (EPRI), which is the research arm of the electric power industry and has numerous coal-burning power plants on the Ohio River, has experimented with interstate water-quality trading. Many watersheds—both large and small—cross state boundaries. In 2012, Ohio and Kentucky formally approved interstate water-quality trading. The Ohio Basin Project has favored reverse auctions and brokering trades using the American Farmland Trust, although it recently started exploring working with SWCDs.

## Regulatory Framework

Water-quality-trading programs require a regulatory driver to be effective. One of the reasons for the initial success of the Alpine case was that the factory wanted to expand its production, but was facing the fact that its phosphorus levels were out of compliance. Also, the factory phosphorus load had been set by the 2000 Sugar Creek TMDL. So, in order for a plant expansion, OEPA required the factory to lower the phosphorus levels from over 200 mg/L to about 3 mg/L before they would be allowed to trade. The calculations were also determined according to the TMDL so that, for expansion, the factory had to lower its concentration or outflow volume. Although the trading plan was formally ready to be implemented in 2006, OEPA required that the facility upgrades be completed so that the factory level would be lowered to at least 3.2 mg/L before trading could begin. Trading was aimed at the 2.2 mg/L remaining, to bring their concentration down to 1.0 mg/L as required by their NPDES permit issued in January 2007.

The renewal of the Alpine Nutrient Trading Plan in 2012 was also based on a pressing need. In this case, they were selling the company to a Scandinavian dairy cooperative and needed to have their regulatory papers in order for the sale to go through. This was also the case with Ohio's fifth trading program, the Walnut Creek water-quality-trading program. The Walnut Creek trading project was located within the Alpine Trading area, so followed the same rules as Alpine and was formed as part of a NPDES permit when the county WWTP was under OEPA pressure for violations on their permit.

There are some cases where regulation is weak or nonexistent. The Miami Plan started at the same time as the Alpine Plan, but, since regulations were not in place, incentives were given to wastewater-treatment plants in anticipation of OEPA applying regulations on phosphorus and nitrogen discharge. The delay of regulations being applied made it difficult for the plan to continue without federal assistance, although they were able to accomplish the reverse auction-bidding process and implement a number of conservation practices. Even in the Muskingum Watershed, much of the northern half of the watershed has TMDLs, whereas the southern half is still working with OEPA to develop them. Because the Ohio rules do not allow banking of credits, it is difficult to find incentives for non-regulated areas to induce participation. The Ohio rules do allow a lower trading ratio for such areas, but that alone probably isn't enough incentive.

## Economic Framework

Finding a balance between the cost of what farmers need to implement conservation measures and what the point sources need to balance their books is not an easy task. Stanton *et al.* (2010) noted the difficulty in comparing prices per pound across trading programs in the United States. A number of factors affect the price such as trading ratios, location, delivery, uncertainty, and retirement. For example, trading for reductions upstream is almost always more beneficial to the ecosystem than trades occurring downstream as a result of their cumulative effect. In some cases, it is economically beneficial for a downstream city to pay to have conservation measures installed upstream so that they don't have to pay the high cost of treating the water, such as the case for high nitrates in the spring for the City of Columbus in Ohio. Also in Ohio we can see the need for different conservation measures in different parts of the state affected by different ecoregions. For example, presently the algal blooms in Lake Erie in NW Ohio need conservation measures directed at soluble reactive phosphorus, whereas in SE Ohio the main environmental issue may be acid mine drainage. Northwest Ohio is flat, glaciated and in the eastern part of the corn belt, whereas SE Ohio is unglaciated and part of the Appalachian foothills, making a direct comparison difficult.

In the Alpine case, we also found that the duration of the conservation measure made pricing difficult. On the surface, the price per pound for the Alpine project looks astronomical compared to other programs. Alpine Cheese company paid $800,000 to cover the payments to the farmers, compensation to the county SWCDs for administrative and technical support, and to OSU for writing the plan and conducting voluntary and mandatory water-quality sampling. But, unlike other programs, about 70% of the conservation practices had a 15–20-year lifespan so that the credits could be sold over that time. This was due to the fact that most of the Alpine Plan area farmers were dairy producers who had manure issues, so most of the pollution remedies addressed manure management and were long term. An example would be creating a manure-storage area.

This compares to the corn belt where a solution might be to start using no-till methods that are paid out to the farmer on a per-acre basis each year.

We have realized that one of the most important factors that affects price and the general structure of a trading plan is the load of an individual point source that might bid for credits. We realized this only after reflecting on why the Alpine case was so successful and why large city WWTPs were struggling with their programs. The reason is simple but fundamental: economy of scale plays a key role. The cost of a facility upgrade per gallon of outflow for a plant like Alpine, with only 0.14 mgd (million gallons per day), is about 4–6 times higher than for a medium-sized town. The cost of facility upgrades for a small town with a population of a few thousand people and a wastewater-treatment plant with outflow of 0.5 to 1 mgd is normally in the $4 million to $7 million range. The other factor to consider is how close the point source is to the target level. If a plant is fairly close to the target level, usually water-quality trading would be easier and cheaper than a facility upgrade. Hartman and Cleland (2007) have provided a useful comparison of WWTP methods and costs for phosphorus removal. For a plant to remove phosphorus down to a 1 mg/L level using AS plus alum, a common method used in the Muskingum Watershed, the cost for a plant with a capacity of 1 mgd was $64,800, whereas the cost for a plant with a capacity of 50 mgd was $1,540,000. The latter figure is slightly less than half on a per-gallon basis. The difference is even greater when the size of the plant drops below 1 mg/L as was the Alpine case. However, transaction costs are also higher for small-scale operations so they need to be factored into the price and are, no doubt, the reason why some of the larger trading plans have been attractive to large WWTPs and large farms to implement the conservation measures.

It is important to realize that ecological economics is based on adding ecological value in a way that complements social and economic values. An example of this is the conservation measure called "fencing exclusion" that was installed on dairy farms and resulted in improving the cheese niche in the area. This is because fencing cows out of the streams resulted in a lower somatic cell count (bacteria) in the milk, so that the local dairy wanted to buy more of their milk due to the higher quality. It also resulted in an increased premium of $0.75/cwt (which amounts to about $22.50/cow/year) that the farmers received for their milk.

The project worked with 25 farmers and installed 91 practices that resulted in 7,133 pounds although only 5,500 were needed for the permit. The cheese-factory expansion added 12 jobs to the local economy and over half of the milk purchased by the factory is local. In addition to phosphorus credits generated, about twice as much nitrogen was remediated through the same conservation practices, but these credits were not sold; the project aims to sell them in the future. In a sense, these were a "free" improvement for the watershed. The project is very popular in the community and a waiting list of farmers exists hoping for future projects, should the Muskingum Plan be approved. Ohio EPA and local residents can also point to the fact that there is a measureable improvement to the Middle Fork where the cheese factory is located. The stream is now in full biological attainment of OEPA standards according to a study of biological monitoring data independently assessed by the Midwest Biodiversity Institute.

## Organization

Both the Alpine and the Muskingum Plans focus on the county SWCDs. A study conducted by Moore *et al.* (2008) showed that farmers trusted their local county SWCD more than any other agency in the watershed. Trust was also a focus of the study by Mariola (2009), who found that farmers liked the local SWCD, "Because they know agriculture and because their mission statements position them as farmer advocates, farmers trust that they will help guide them through the conservation process without the threat of increased regulation." There is another reason why local SWCDs make sense when small-town WWTPs are the focus. Many county SWCDs and county WWTPs, such as was the Walnut Creek case, are financed and managed through the county commissioners. So, from a county level, it makes sense to save money on the WWTP upgrade and share that savings to finance the SWCD and also return tax savings to the citizens. We also found that most of the SWCD employees had farming backgrounds so that the technicians' local knowledge was respected, and it was easy for them to communicate and advocate for the program.

## Ecological Approach

The Alpine Project and the Sugar Creek Project, of which it is a part, are based on ecological science. As such, the emphasis is on understanding and bringing back ecological structure and function to headwaters. According to Alexander *et al.* (2007), first-order headwater streams contribute approximately 70% of the mean-annual water volume and 65% of the nitrogen flux in second-order streams. During the Alpine Project, the county SWCD technicians first ranked the possible conservation measures for each farm and the cost of phosphorus reduction. Next they consulted with the farm family about which of the conservation measures they preferred. Usually the final conservation measures that were selected represented a combination of those that produced the most phosphorus reduction per dollar and those that the farm family wanted but were not quite as cost effective, or had more ecological importance.

## Conclusion

The future of water-quality trading in Ohio will depend on the severity of the algal blooms and hypoxia in Lake Erie and the Gulf of Mexico, respectively. Ohio is a state with several contrasting water-quality-trading programs that differ in scale and approach. The Alpine Cheese Nutrient Trading Plan has for various reasons fully accomplished the goals of the Alpine Cheese Company NPDES permit. While it is likely that the renewal of the permit and trading plan for another five years will be equally successful and even carried out at a lower price, whether or not the Muskingum Plan can replicate the success at a much larger scale in 21 counties in Ohio remains unknown. Likewise, much of what happens with water-quality trading in Ohio depends on the extent to which the nutrients are regulated. For example, numeric nutrient criteria have been introduced in several states and Ohio EPA plans to adopt them within the next few years. The lower levels of phosphorus and new rules for nitrogen may encourage more water-quality-trading efforts to meet the new standards.

## References


Alexander R *et al.* (2007) The role of headwater streams in downstream water quality. Journal of the American Water Resources Association 43 41–59.

Hartman P Cleland J (2007) Wastewater Treatment Performance and Cost Data to Support an Affordability Analysis for Water Quality Standards. http://www.kysq.org/docs/Wastewater_2007.pdf.

Mariola M (2009) Are Markets the Solution to Water Pollution? A Sociological Investigation of Water Quality Trading. Ohio State University: PhD Dissertation.

Moore R *et al.* (2008) Agricultural sustainability and water pollution: Lessons from the Sugar Creek farmers in Ohio. Culture and Agriculture 30(1–2) 3–16.

Selman M *et al.* (2009) Water Quality Trading Programs: An International Overview. Washington, DC: World Resources Institute.

Stanton T *et al.* (2010) State of Watershed Payments: An Emerging Marketplace. Ecosystem Marketplace. http://www.foresttrends.org/documents/files/doc_2438.pdf.

US Environmental Protection Agency (2003) Water Quality Trading Assessment Handbook: EPA Region 10's Guide to Analyzing Your Watershed. Washington, DC: US Environmental Protection Agency.

Willamette Partnership (2012) In it Together: A How-To Reference for Building Point-Nonpoint Water Quality Trading Programs. Hillsboro, OR: Willamette Partnership.

**RICHARD MOORE** is the executive director of Interdisciplinary Environmental Sciences at The Ohio State University and lead author of the Alpine Nutrient Trading Plan and Muskingum Water Quality Trading Plans. These plans are based on water-quality trading in upstream areas with maximum ecological benefit and cost-savings for small communities and industries with high wastewater facility-upgrade costs. He is president of the Culture and Agriculture Section of the American Anthropological Association. Dr. Moore's specialty is social organization and rural communities in Ohio and Japan. His dissertation work focused on upstream-downstream social relations in the rice belt of Japan. He is presently a principal investigator on a number of NSF, USDA, and EPA grants that focus on water quality and climate change. He also serves as assistant director of the School of Environment and Natural Resources and is involved in transdisciplinary programs at the Ohio Agricultural Research and Development Center (OARDC).

# *Agriculture and Sustainable Practices: Protecting Water Quality*

D. Osmond[1], D. Meals[2], D. Hoag[3], M. Arabi[3], A. Luloff[4], M. McFarland[5], G. Jennings[1], A. Sharpley[6], J. Spooner[1] and D. Line[1]

[1]*North Carolina State Univ.*
*Raleigh, North Carolina*

[2]*Ice.Nine Environmental Consulting*
*Burlington, Vermont*

[3]*Colorado State Univ.*
*Fort Collins, Colorado*

[4]*The Pennsylvania State Univ.*
*University Park, Pennsylvania*

[5]*Texas A&M University*
*College Station, Texas*

[6]*Univ. of Arkansas*
*Fayetteville, Arkansas*

dosmond@ncsu.edu

Conservation practices are used to protect vital resources, such as soil and water, while maintaining productive agriculture. Scientists have conducted hundreds of research projects on conservation practices over decades and the volume of research is evident in the compilation of bibliographies by the Water Quality Information Center at the National Agricultural Library, in conjunction with the USDA, to support the Conservation Effects Assessment Project (CEAP) (Gagnon *et al.*, 2004; Maderik *et al.*, 2006a, 2006b; Gagnon *et al.*, 2008).

The CEAP was created in 2003 to understand and optimize environmental benefits of conservation practices implemented via selected US Department of Agriculture (USDA) conservation programs. Cooperators involved in this USDA project included the Natural Resources Conservation Service (NRCS), Agricultural Research Service, National Institute of Food and Agriculture (NIFA), and the Farm Service Agency. Overall, the goal of CEAP is to improve the efficacy of conservation practices and programs by quantifying conservation effects and providing the science and education base needed to improve future conservation planning, implementation, management decisions, and policy (Duriancik *et al.*, 2008).

As part of the overall CEAP initiative, NIFA and NRCS funded 13-watershed scale agricultural projects (2004 to 2006) to focus on relating water-quality change to conservation-practice implementation on crop and pasture land (Figure 1).

These 13 projects, herein called NIFA-CEAP, were retrospective studies. In order to be funded they were required to have smaller-scale watersheds (8–12 HUC[1]), a long-term (>5 years) record of water-quality data, and georeferenced land use and conservation practice information. In addition, each project watershed was expected to use socio-economic analysis to better understand the factors that influenced adoption of practices by farmers. Each project was expected to answer these four questions:

- How do the timing, location, and suite of implemented agricultural conservation practices affect water quality at the watershed scale?
- How do conservation practices implemented in a watershed interact with respect to their effects on water quality?
- What social and economic factors facilitate or impede implementation of conservation practices? and
- What is the optimal set of conservation practices and their optimal placement within the watershed needed to achieve water-quality goals? (Model development and use were expected to address this question.)

The 13 projects selected for funding represent diverse agroecological environments across the United States, and all the projects produced a rich set of scientific results presented in many peer-reviewed articles, including a special issue of the November/December 2010 *Soil and Water Conservation Journal.*

## Methods

In 2007, NIFA (then CSREES) and NRCS funded a synthesis of the overall NIFA-CEAP watersheds studies in order to integrate and extend lessons learned from the 13 watersheds. Multiple sources of information (*e.g.*, publications, presentations, factsheets) derived from the projects were integrated into a site description (Osmond *et al.*, 2012). A key informant interview questionnaire was used at each watershed location, with a minimum of six to a maximum of 26 interviewees. Of the 196 key informants, 34 farmers, 33 university/extension affiliates, 23 representatives of federal agencies, 10 representatives of state agencies, 28 representatives of local agencies, 24 representatives of local businesses or newspapers, 11 local residents, and 11 elected officials were interviewed. Lessons were developed from each of the 13 projects and then synthesized by functional areas: key informants, land treatment, water-quality monitoring, modeling, socioeconomics, and outreach. Only lessons for land treatment will be presented in this paper. For more detail, see Osmond *et al.* (2012).

## Results and Discussion

The major question for land treatment is, what would make conservation-practice implementation better? First and foremost for effective protection of water, conservation

---

[1]Hydrologic unit codes.

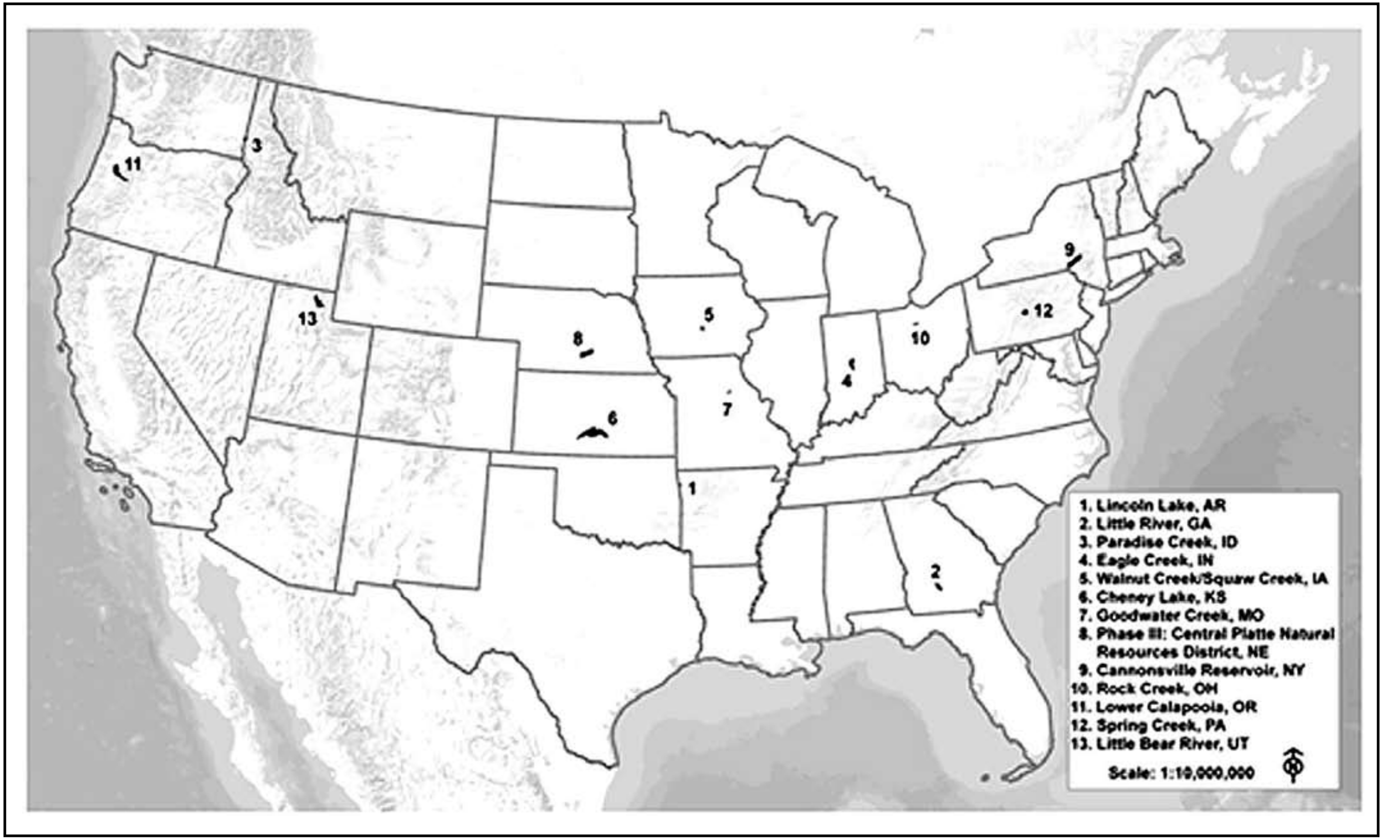



Figure 1. National Institute of Food and Agriculture Conservation Effects Assessment Project locations.

planning must occur at the watershed scale rather than in counties, and there must be sufficient water-quality and potentially modeling information. Before conservation practices are implemented, it is critical to understand the pollutant of concern and pollutant sources and then determine the appropriate conservation practice(s). Several NIFA-CEAP studies found that sediment-reducing conservation practices (*e.g.*, conservation tillage or terraces, grassed waterways and drains) were the predominant practices used when the primary pollutant of concern was nitrate in the groundwater. These sediment-reducing practices can actually increase nitrate leaching. Also, in most watersheds where sediment was of concern, such as Idaho and Iowa, researchers found that the uplands had been well treated for soil loss but that much of the sediment was coming from the streams; under these projects, stream banks were not treated.

Once the appropriate conservation practice is selected, it should be targeted to the critical source area(s). Critical source area(s), that portion of the watershed that delivers the majority of the pollutant, may vary for different pollutants (Meals *et al.*, 2012). In addition, often conservation practices are not directed to these important areas. The Kansas, Missouri, and Utah NIFA-CEAP studies determined critical source areas using different methods and found that, on average, only 25% of the conservation practices were installed in these locations.

Once watershed planning has occurred, the pollutant and source are understood, and the critical source areas identified, it is then critical to work with farmers for adoption of conservation practices. During the key-informant interviews, we found that farmers obtain most of their information from each other (farmer-to-farmer) or from local trusted officials. Conservation work with farmers is very personnel-intensive, as many factors affect farmers' decisions about which practices to use. These factors consist of profit, yield, ease of use, technological development, type of practice, and intangible reasons. Management practices were found to be more difficult for farmers to implement and sustain than structural practices. For instance, terraces were maintained better relative to nutrient-management use. Farmers often told us that conservation-tillage adoption was due to new technologies (planters, herbicides, and genetically modified seed) and reduced labor needs. In addition, it is easier for farmers to understand the impact of soil loss than nutrient loss. As a consequence, there was greater adoption of conservation practices that control sediment than nutrients. Several of the watersheds (Arkansas, Nebraska, New York) were threatened or under regulatory guidelines. Farmers in these watersheds were more aware and often more willing to adopt conservation practices. However, additional money was also spent in these watersheds. Since conservation-practice adoption is a multivariate and individualistic choice, it is critical that conservation planners work closely with farmers to increase adoption.

From the NIFA-CEAP synthesis, it is clear that conservation planning and implementation to protect water quality must be more intentional if we are to protect water quality and use our financial resources more wisely. Protection of water quality through the use of conservation practices must be the responsibility not only of federal and state agency personnel, but also farmers, agricultural businesses, and nonprofit organizations.

## Acknowledgments

The authors appreciate the funding supplied by USDA National Institute for Food and Agriculture (NIFA) and Natural Resources Conservation Service (Agreement No. 2007-51130-18575) and all of the help given by the 13 NIFA-CEAP project personnel.

## References

Duriancik L *et al.* (2008) The first five years of the Conservation Effects Assessment Project. Journal of Soil and Water Conservation 63 185A–188A.

Gagnon S *et al.* (2004) Environmental Effects of U.S. Department of Agricultural Conservation Programs: A Conservation Effects Assessment Project (CEAP) Bibliography. Special Reference Briefs Series no. SRB 2004-01. Beltsville, MD: Water Quality Information Center, National Agricultural Library, Agricultural Research Service, USDA.

Gagnon S *et al.* (2008) Effects of Agricultural Conservation Practices on Fish and Wildlife: A Conservation Effects Assessment Project (CEAP) Bibliography. Special Reference Briefs Series no. SRB 2008-01. Beltsville, MD: Water Quality Information Center, National Agricultural Library, Agricultural Research Service, USDA.

Maderik R *et al.* (2006a) Environmental Effects of Conservation Practices on Grazing Lands: A Conservation Effects Assessment Project (CEAP) Bibliography. Special Reference Briefs Series no. SRB 2006-02. Beltsville, MD: Water Quality Information Center, National Agricultural Library, Agricultural Research Service, USDA.

Maderik R *et al.* (2006b) Wetlands in Agricultural Landscapes: A Conservation Effects Assessment Project (CEAP) Bibliography. Special Reference Briefs Series no. SRB 2006-01. Beltsville, MD: Water Quality Information Center. National Agricultural Library USDA Agricultural Research Service.

Meals D *et al.* (2012) Lessons Learned from the NIFA-CEAP:Identifying Critical Source Areas. http://www.soil.ncsu.edu/publications/NIFACEAP/Factsheet_7.pdf.

Osmond D *et al.* (2012) How to Build Better Agricultural Conservation Programs to Protect Water Quality: The NIFA-CEAP Experience. Ankeny: Soil and Water Conservation Society.

**DEANNA OSMOND** works at the interface of nutrient management and water quality as both a researcher and an extension specialist at the state and national levels. For the past 20 years, Dr. Osmond has worked at NC State University, first with the Water Quality Group of Biological and Agricultural Engineering and then in the Soil Science Department. She received her bachelor's degree from Kansas State in agronomy and anthropology. After working on a dairy farm, she received her master's degree from NC State University in soil science. For several years she worked in Africa as an international project officer for the US Agency for International Development. Her PhD was awarded from Cornell.

# *Agricultural Management, Water Quality and Ecology: Putting Practice into Policy*[1]

Andrew Sharpley
*University of Arkansas*
*Fayetteville, Arkansas*

Helen Jarvie
*National Centre for Ecology & Hydrology*
*Wallingford, United Kingdom*

sharpley@uark.edu / hpj@ceh.ac.uk

Since the late 1960s, point sources of water-quality impairment have been reduced due to their ease of identification and the passage of the Clean Water Act in 1972. However, water-quality problems remain, and as further point-source control becomes less cost-effective, attention is being directed towards the role of agricultural nonpoint sources in water-quality degradation. In a 1996 US Environmental Protection Agency (EPA) report, nonpoint-source nutrients were the primary source of concern in 40% of rivers, 50% of lakes, and 60% of estuaries surveyed and listed as impaired (US Environmental Protection Agency, 1996). Some 15 years on, continuing water-quality impairment has led to major initiatives to reduce losses from the Chesapeake Bay Watershed (Kovzelove *et al.*, 2010; US Environmental Protection Agency, 2010a) and the Mississippi River Basin (National Research Council, 2008). As in the United States, the European Union Water Framework Directive (WFD) (Council of European Communities, 2000) requires widespread control of nitrogen (N) and phosphorus (P) inputs to rivers specifically to improve riverine ecology (Hilton *et al.*, 2006).

Phosphorus inputs to fresh waters can accelerate eutrophication (Carpenter *et al.*, 1998). Although nitrogen and carbon (C) are also essential to the growth of aquatic biota, most attention has focused on P because of the difficulty in controlling the exchange of N and C between the atmosphere and water, and fixation of atmospheric N by some blue-green algae (Schindler *et al.*, 2008). Thus, control of P inputs is critical to reducing freshwater eutrophication. For water bodies with naturally higher salt content, as in estuaries, there are likely unique site-specific critical concentrations of both N and P that generally limit aquatic productivity (Howarth *et al.*, 2000).

[1]A combination of presentations: *Agricultural Management and Water Quality: Putting Practice into Policy* by Andrew Sharpley and *Murky Waters: Linking Nutrient Sources and Impacts in Watersheds* by Helen Jarvie.

Eutrophication has been identified as the main problem in surface waters having impaired water quality (US Environmental Protection Agency, 2002). Eutrophication restricts water use for fisheries, recreation, industry, and drinking, due to the increased growth of undesirable algae and aquatic weeds and oxygen shortages caused by their death and decomposition (Table 1). Also, many drinking-water supplies throughout the world exhibit periodic massive surface blooms of cyanobacteria. These blooms contribute to a wide range of water-related problems including summer fish kills, unpalatability of drinking water, and formation of trihalomethane during water chlorination. Outbreaks of the dinoflagellate *Pfiesteria piscicida* in the eastern United States were linked to excess nutrients in affected waters (Burkholder and Glasgow, 1997).

Nitrate is a water-quality concern because it has been linked to methemoglobinemia in infants, to toxicities in animals, and to increased eutrophication in both fresh and saline (*e.g.*, estuaries) waters. In response, EPA has established a maximum contaminant level for nitrate-N in drinking water of 10 mg $L^{-1}$ (45 mg nitrate $L^{-1}$). Under anaerobic soil conditions, denitrifying bacteria readily convert excess nitrate to N gases (primarily $N_2$), reducing the quantity of nitrate that can potentially leach to groundwater supplies. However, the production of $N_xO$ gases contributes to the accumulation of greenhouse gases in the atmosphere (Figure 1).

*TABLE 1. ADVERSE IMPACTS OF EUTROPHICATION ON FRESHWATER LAKES, RIVERS, AND STREAMS.*

| |
|---|
| Increased phytoplankton biomass |
| Shifts in phytoplankton to bloom-forming species that may be toxic or inedible |
| Increased biomass of benthic and epiphytic algae |
| Changes in macrophyte species composition and Biomass |
| Decreases in water transparency |
| Taste, odor, and water-treatment problems |
| Oxygen depletion |
| Increased incidence of fish kills |
| Loss of desirable fish species |
| Reductions in harvestable fish and shellfish |
| Decreases in aesthetic value of water body |

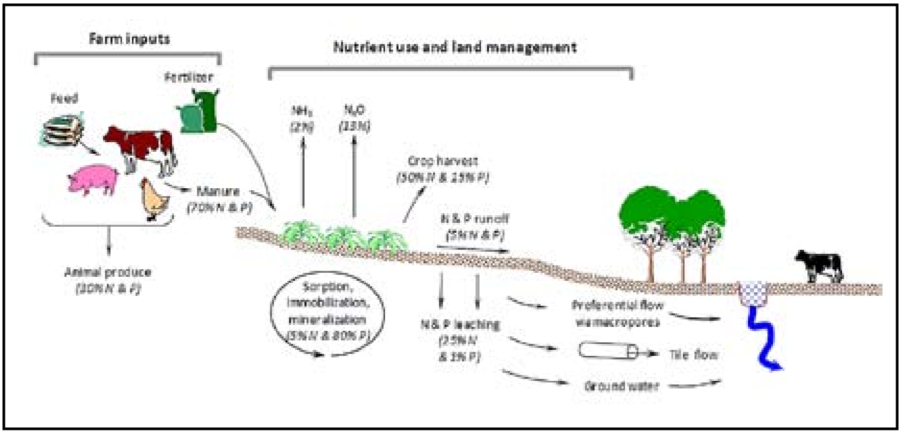



Figure 1. Factors affecting the fate of N and P in agriculture, representing their potential impact on soil, water, and air quality. Numbers in parentheses are based on an approximate farm nutrient balance and relative fate of N and P as a percentage of load ("Farm inputs") or percentage of fertilizer and manure ("Nutrient use and land management") (adapted from Duxbury *et al.*, 1993; Bouwman and Booij, 1998; Howarth *et al.*, 2000; Sims and Sharpley, 2005).

In the last 20 years, there has been a "U-turn" in strategic planning for nutrient management and water-quality impacts. It is now cheaper to treat the cause of water-quality impairment rather than its effects. In the early 1990s for example, New York City decided it would be more cost-effective to identify and target for remediation, the sources of P in its water-supply watersheds, rather than build a new \$8-billion water-treatment facility. As a result, the state invested \$10 million to identify and reduce nutrient sources in its supply watersheds. A similar targeted management strategy is now in place in most impaired waters of the United States, as, for example, in the Chesapeake Bay Watershed, Florida inland and coastal waters, Lake Erie Basin, and Mississippi River Basin.

Phosphorus and N are typically treated separately by scientists and environmental managers. The theoretical parsing of these elements may be partly attributed to the differing mobilities of P and N in soils; P is often insoluble and primarily transported in erosion and runoff, whereas N is highly soluble and readily leached. Even so, such a separation is artificial as P and N occur simultaneously in watersheds and farmers manage them together. Thus, as we move forward to remediate water quality, both N and P must be considered in concert.

## The Evolution of Agricultural Systems

Post-WWII improvements in agriculture have dramatically increased grain and protein production in a very cost-effective manner. The specialization and fragmentation of crop and animal-production systems, however, has brought new pressures to bear on agricultural management within watersheds. Watersheds generally had a sustainable nutrient balance, whereas nutrients are now moved, either as inputs (fertilizer and feed products) or produce on a global scale, which brings new pressures, challenges and therefore, solutions. For instance, increased grain and animal production in Brazil is making inroads into traditional US markets and US producers supply a large percent of the meat consumed in Japan as water-quality constraints in Japan limit cost-effective production there.

As a consequence of the spatial separation of crop and animal-production systems, fertilizers are produced (*i.e.*, N) or imported (*i.e.*, P) to areas of grain production (Figure 2). The grain and harvested N and P are then transported to areas of animal production, where inefficient animal utilization of nutrients in feed (<30% utilized) results in their excretion as manure. This has led to a large-scale, one-way transfer of nutrients from grain- to animal-producing areas that crosses watersheds and even national boundaries and has dramatically broadened the emphasis on watershed-management strategies (Figure 2).

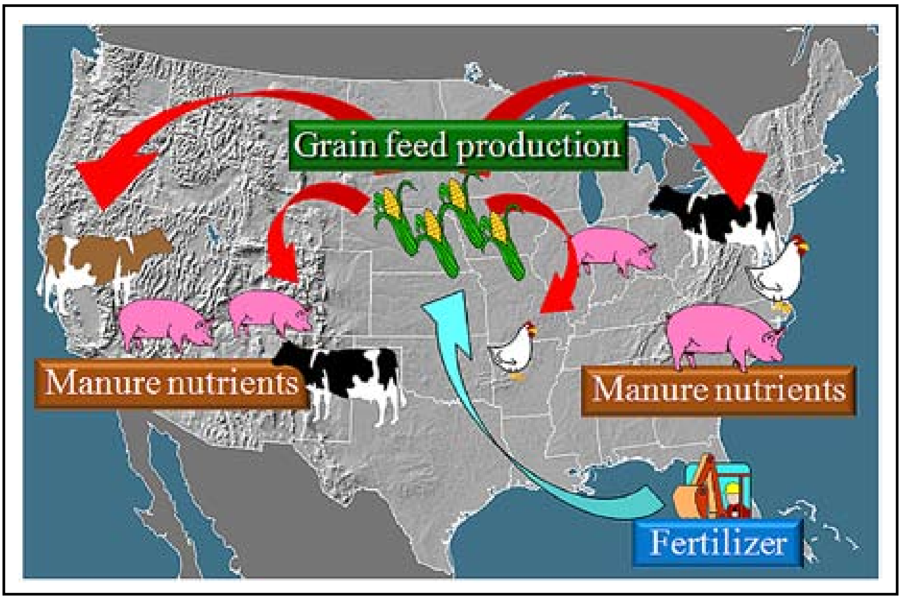



Figure 2. Grain- and animal-production systems have evolved in spatially separate areas leading to localized accumulations of nutrients in manure.

In general, watersheds dominated by animal-feeding operations (AFOs) have become net sinks for nutrients imported in fertilizer to apply to local crops or in animal feed, as animals utilize <30% of the nutrients they are fed. Consequently, watersheds that include AFOs determine the magnitude of nutrient surpluses at farm and watershed scales depending on the type and intensity of livestock operations and the land area available for spreading of the manure produced. For example, the potential for N and P surpluses on farms with AFOs can be much greater than in cropping systems where nutrient inputs become dominated by livestock feed rather than fertilizer purchased explicitly for application to crops. As the intensity of animal production within a watershed increases, more P must be recycled, the P farm surplus (input-output) becomes greater, soil P levels increase, and the overall risk of nutrient loss tends to increase (Pote *et al.*, 1996; Haygarth *et al.*, 1998; Sharpley, 2000; Torbert *et al.*, 2002; Daverede *et al.*, 2003; Withers *et al.*, 2003).

## The Fate of N and P in Agriculture

The fate of N and P in agriculture is depicted in Figure 1. Approximate percentage inputs of N and P, as feed or fertilizer, and their respective fate when fed to animals or applied to land, were obtained from several studies, as summarized below.

### *Nitrogen*

In rain-fed systems, an average of 40 to 60% of the N applied in fertilizer and manure is removed in crop harvest (Figure 1; Howarth *et al.*, 2000). Of the remainder, varying amounts are stored as organic N in the soil, volatilized to the atmosphere, and leached. A variety of factors, including soil properties, climate, fertilizer, manure, and land management, influence the fate of applied N (Howarth *et al.*, 1996). For typical rain-fed farming in the United States, roughly 15% of field-applied N is volatilized to the atmosphere as ammonia and $N_xO$ (Figure 1). This N is deposited back onto the landscape, often near the source of volatilization, although sometimes traveling long distances within an airshed (Holland *et al.*, 1999). Again, for typical farming systems in the United States, the percentage of applied N that leaches varies between 10 and 40% for loam and clay soils, and 25 and 80% for sandy soils (Howarth *et al.*, 1996).

### *Phosphorus*

Several soil and crop factors, including soil-P-sorption capacity, crop type, P-application type, method and rate, and land management, influence plant uptake of P (Pierzynski and Logan, 1993; Sims and Sharpley, 2005). Phosphorus loss by leaching is generally greater in sandy, organic, or peaty soils—those with low P-adsorption capacities—and in soils with substantial preferential flow pathways (Sharpley and Syers, 1979; Bengston *et al.*, 1988; Sims *et al.*, 1998) (Figure 1). Phosphorus transport in surface runoff is generally greater than in subsurface flow, depending on: the rate, time, and method of P application; form of fertilizer or manure applied; amount and time of rainfall after application; and land cover (Sharpley and Rekolainen, 1997). While P loss from tile-drained soils receiving manure is generally low, there has been a dramatic increase in the extent of tile drainage since 2005 in the Lake Erie Basin, which has connected more fields to ditches and streams and, along with a major shift to no-till cropping, has contributed to increased inputs of P to Lake Erie (Richards *et al.*, 2010).

## Remedial Measures

Many beneficial management practices (BMPs) can be implemented over a wide range of scales to minimize the loss of N and P from agriculture to surface and ground waters (Table 2). These are commonly grouped into measures that seek to reduce the inputs of

*Table 2. Beneficial management practices to minimize the loss of N and P from agriculture.*

| Practice | Description | Impact on loss[¶] N | P |
|---|---|---|---|
| **Farm Inputs** | | | |
| Crop hybrids | Low phytic-acid corn reduces P in manure | neutral | decrease |
| Feed additives | Enzymes increase nutrient utilization by animals | decrease | decrease |
| Feed supplements | Match animals nutritional requirements | decrease | decrease |
| **Source Management** | | | |
| Crop requirements | Nutrient applications based on crop N &/or P needs | decrease | decrease |
| Pre-sidedress N Test | PSNT can aid accurate split N applications | decrease | neutral |
| Soil P testing | Nutrient applications based on soil P availability | neutral | decrease |
| Tissue testing | N applications can be tailored to crop needs | decrease | neutral |
| Cover crops/residues | If harvested can reduce residual soil nutrients | decrease | decreaseTP increase DP |
| Site-specific management | Use of GIS & GPS to apply and manage nutrient sources | decrease | decrease |
| Method of application | Incorporated, banded, or injected in soil | decrease | decrease |
| Rate of application | Match crop needs | decrease | decrease |
| Source application | Sources can differ in their P & N availability | decrease | decrease |
| Timing of application | Avoid application to frozen ground Apply during season with low runoff probability | decrease | decrease |
| **Transport Management** | | | |
| Conservation tillage | Reduced and no-till increases infiltration and reduces soil erosion | decreaseTN increase$NO_3$ | decrease TP increase DP |
| Strip cropping, contour tillage, terraces | Reduces transport of sediment-bound nutrients | decreaseTN neutral $NO_3$ | decrease TP neutral DP |
| Conservation cover | Permanent vegetative cover increases soil infiltration and water holding capacity | decrease | decrease |
| Invert stratified soils | Redistribution of surface P through profile by plowing | neutral | decrease |
| Buffer, riparian, wetland areas, grassed waterways | Removes sediment-bound nutrients, enhances denitrification | decrease | decrease TP neutral DP |
| Critical source area | Target sources of nutrients in a watershed for treatment | decrease | decrease |

N and P onto farms and bring them into closer balance with outputs in produce; manage on-farm nutrient sources through appropriate rate, timing, and method of N and P application; and measuring the potential for N and P transport to surface and ground waters (Table 2). These measures are also depicted in Figure 3.

## *Remedial Input Decisions*

Carefully matching dietary inputs to animal requirements can reduce the amount of P excreted. In a survey of Wisconsin dairy farms, Powell *et al.* (2001) found that decreasing dietary P from an excessive 0.55% P to the NRC-recommended level of 0.36% P would reduce by about two thirds the number of farms and acreage with an excess P balance (Powell *et al.*, 2002). Implementing a carefully planned diet tailored to meet the specific

[¶]TN is total N, $NO_3$ is nitrate, TP is total P, and DP is dissolved P.

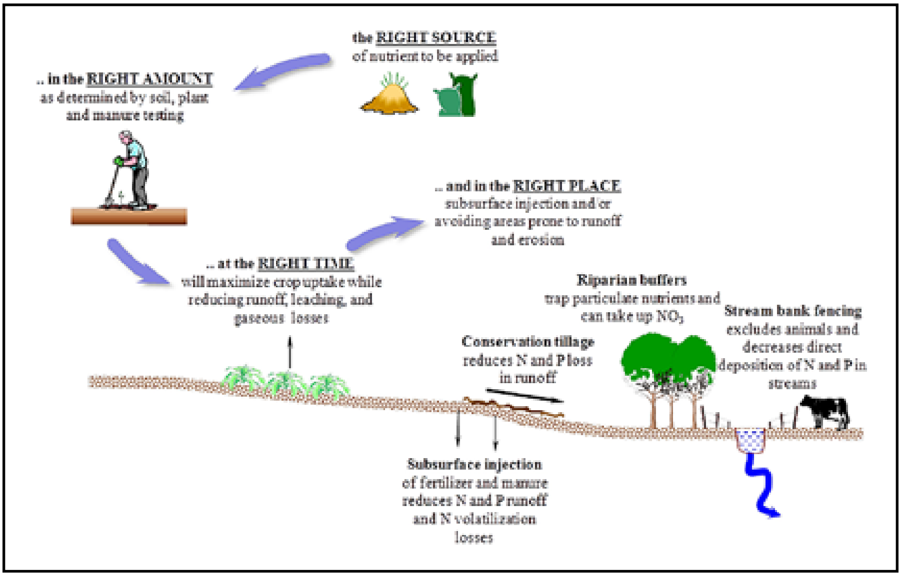



Figure 3. The management of N and P in agricultural systems.

N and P requirements of animals in each phase of their growth will minimize nutrient loss to the environment in feces, urine, and gases. Reducing farm inputs of N and P in animal feed is a very effective BMP that can contribute to bringing about lasting decreases in N and P losses to the environment. In fact, other nutrient-management measures (Table 2) are generally aimed at decreasing the potential for N and P losses and are seen as short-term "band aids" and not solutions.

## *Nutrient Management*

Careful nutrient-management planning on a field-by-field and farm basis is a major component of any remedial action plan to minimize the risk of nutrient loss from agricultural lands. This basically follows the traditional "4R" nutrient management approach, which is adding the Right form of nutrient, at the Right rate to match crop needs, at the Right time, and in the Right place (Figure 3).

*The Right Source* Fertilizer N, P, and K can be formulated to match crop needs; however, manures have relatively more P than N compared with crop requirements. For instance, the ratio of N:P in manure (2 to 4:1) is about three to four times lower than that taken up by major grain and hay crops (8:1) (Figure 4). As a result, application of manure to crops on an N-basis, where the N requirements of the crop are met by manure, over-applies P three to four times than that taken up annually by the crop (Figure 4). Repeating N-based manure applications over a number of years will eventually increase soil P levels above those optimum for crop needs, increase the source of P, and thereby the potential for increased P runoff. On the other hand, application of manures based on the P requirements of the crop will generally apply insufficient N to meet crop needs (Figure 4). The under application of N is a major economic drawback to P-based-manure applications, as farmers are forced to purchase costly mineral N fertilizer to offset the N shortfall.

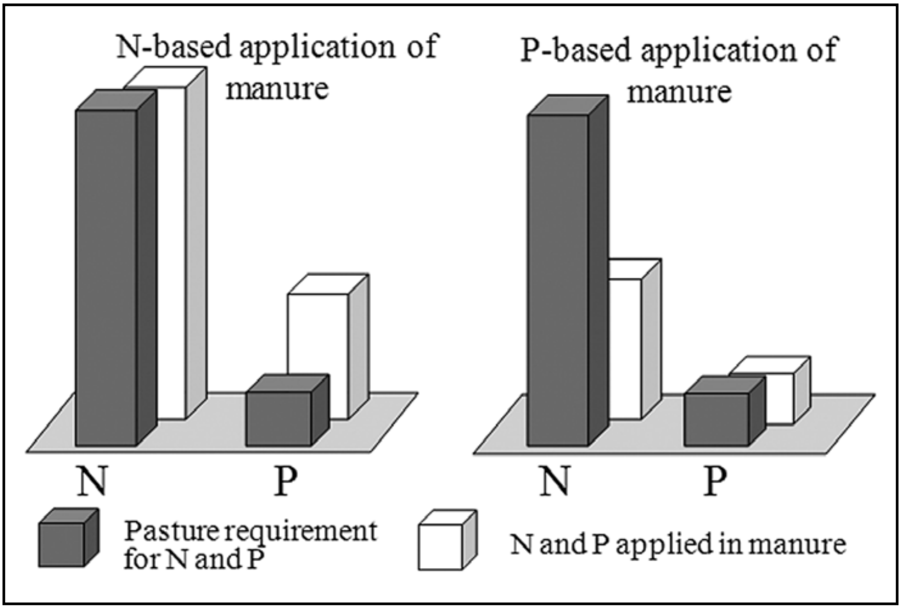



Figure 4. The manure-nutrient balancing dilemma.

*The Right Rate* Considerable attention has been given to developing soil-N tests for corn, with the preplant nitrate test successfully used in semi-arid regions of the Western and Great Plains (Hergert, 1987); however, the preplant nitrate test does not work well in more humid regions. A modified approach to the preplant assay was proposed by Magdoff *et al.* (1984) to be used in the more humid corn-production areas, known as the pre-sidedress soil-nitrate test to determine if and how much N fertilizer is needed to supplement any early-season N mineralization.

Because N availability is a function of multiple processes within the soil, varying spatially and temporally, more recent research efforts have focused on methods that evaluate the N status of the growing crop. Varvel *et al.* (1997) demonstrated that chlorophyll meters could be used as an index for N status in corn, and N-fertilizer-use efficiency could be improved with this technique. Remotely sensing crop reflectance has been successfully used in a similar capacity, detecting N deficiency (Osborn *et al.*, 2002) and using an index for developing N recommendations.

Fertilizer-P rates are usually established by crop need and modified by the amount already in the soil, as determined by established soil-test P methods (Cox, 1994). In the case of commercial fertilizer P, applications can easily be tailored to match crop needs and minimize excessive soil-P accumulation, because an economic disincentive exists to avoid applying too much costly fertilizer.

*The Right Time* Nitrogen fertilizer should be applied as close as possible to the time of maximum crop needs and uptake. This minimizes leaching below the root zone and gaseous losses via denitrification and, consequently, should result in the greatest proportion of applied N used by the crop. Although farmers might recognize this situation, deciding when to apply fertilizer depends upon logistical and time constraints unique to every farm. Often, N fertilizer is applied much earlier than required by the crop. In the upper Midwest and Northeast, farmers sometimes are faced with the need to apply N fertilizer on frozen soils. As a general rule, fertilizer should be applied when runoff potential is low.

Many studies show the loss of P in runoff relates directly to the rate and frequency of applied P (Sims and Kleinman, 2005; Sharpley et al., 2007). Avoiding applications within a few days of expected rainfall can minimize runoff losses (Sims and Kleinman, 2005). Several studies show, for example, reductions in N and P losses with an increase in the length of time between manure application and surface runoff (Westerman *et al.*, 1983; Edwards and Daniel, 1993; Sharpley, 1997; Djodjic *et al.*, 2000). These reductions can be attributed to the reaction of added P with soil and dilution of applied P by infiltrating water from rainfall that did not cause surface runoff.

Rainfall intensity and duration, as well as when rainfall occurs relative to when manure is applied, all are factors that influence the concentration and overall loss of manure N and P in runoff. The relationship between potential loss and application rate, however, is critical to establishing BMP strategies. Whereas soil P clearly is important in determining P loss in surface runoff, the rate and frequency of applying P to soil can override soil P in determining P loss (Sharpley *et al.*, 2007). Also evident are the long-lasting effects of applied manure on increased concentrations of P in surface runoff. For instance, Pierson *et al.* (2001) found that applying poultry litter to pastures at N-based rates, elevated runoff P for up to 19 months after application.

*The Right Place* Nitrogen fertilizers are applied by various methods, including injection, broadcasting, banding, and with irrigation water. The method selected usually depends upon machinery, fertilizer type, and compatibility with a farmer's overall crop-management practices and usually has little impact on crop response to or environmental impact of the fertilizer. There are three exceptions: (1) when urea is applied to the soil surface, especially in no-till, (2) when N fertilizer is band-applied or injected into a micro-feature that improves localized water infiltration, and (3) when N fertilizer is sprinkler-applied on sandy soils.

Urea applied to the soil surface is susceptible to considerable loss as volatilization of ammonia gas (as much as 30% of applied N; Fox *et al.*, 1986). Urea volatilized as ammonia poses an environmental risk as atmospheric ammonium fallout. Ammonium deposition poses an environmental threat to pristine ecosystems that are sensitive to slight changes in N inputs (*e.g.*, estuaries or native forests); on the other hand, the impact of ammonia volatilization from urea fertilizers on such ecosystems is not fully understood. However, because of the relative immobility of P in the soil profile, placement of fertilizer P generally is more critical for plant availability than in the case of fertilizer N.

The incorporation of manure into the soil profile, either by tillage or subsurface placement, reduces the potential for P runoff. Rapid incorporation of manure also reduces ammonia volatilization and potential loss in runoff, as well as improving the N:P ratio for crop growth. For example, Mueller *et al.* (1984) showed that incorporation of dairy manure by chisel plowing reduced loss of total P (TP) in runoff from corn 20-fold, compared to no-till areas receiving surface applications. In fact, P loss in runoff declined because of a lower concentration of P at the soil surface and a reduction in runoff with incorporation of manure (Mueller *et al.*, 1984; Pote *et al.*, 1996).

## Transport Management

Transport management refers to efforts to control the movement of P from soils to sensitive locations such as bodies of fresh water.

### *Runoff Potential*

The potential for runoff from a given site is important in determining the loss of P and, to a lesser extent, N, and is thus a critical component of nutrient-management strategies. Distance from where runoff is generated to a stream channel influences N and P loss and, thus, must be a nutrient-management consideration (Gburek and Sharpley, 1998). Runoff, and nutrients carried by it, can be reduced or even intercepted by infiltration and deposition, respectively, prior to reaching a stream channel. Generally, the further a field is from a stream channel the lower the potential for runoff to contribute nutrients to the stream. Therefore, many states have adopted the premise of implementing more restrictive nutrient-management strategies, particularly for P, on fields close to streams.

### *Erosion Potential*

Phosphorus loss via erosion may be reduced by conservation tillage and crop-residue management, buffer strips, riparian zones, terracing, contour tillage, cover crops and impoundments (*e.g.*, settling basins). These practices tend to reduce rainfall impact on the soil surface, reduce runoff volume and velocity, and increase soil resistance to erosion.

### *Permanent Vegetation*

Keeping land in permanent cover, such as grass or cover crops, reduces the risk of runoff and erosion, increases infiltration, and thereby minimizes losses of N and P. Cover crops protect the soil surface from raindrop impact, improve infiltration relative to bare soil, and trap eroded soil particles (Sharpley and Smith, 1994). Where dissolved P transport is the primary concern, cover crops may reduce runoff and, consequently, runoff-P load. Cover crops are unlikely to affect dissolved P concentrations in runoff, however. Kleinman *et al.* (2005) found that cover crops reduced TP concentration in springtime runoff to 36% of the dissolved P in runoff from conventional corn. But dissolved-P concentration was not significantly different between cover crops and conventional corn because it was controlled by soil-P content rather than by soil erosion.

Grassed waterways are designed to trap sediment and reduce channel erosion. In some cases, waterways are installed as cross-slope diversions to intercept runoff and reduce effective slope length. Chow *et al.* (1999) estimated that installation of grassed waterways and terraces in combination reduced annual soil erosion 20-fold in a New Brunswick, Canada, potato field.

### *Riparian/Buffer Areas*

Healthy riparian areas can reduce N and P export, increase wildlife numbers and diversity, and improve aquatic habitats. In addition to acting as physical buffers to sediment-bound nutrients, plant uptake captures N and P, resulting in short-term and long-term accumulations of nutrients in biomass (Peterjohn and Correll, 1984; Groffman *et al.*, 1992; Uusi-Kämppä, 2000). Enhanced denitrification in riparian areas can reduce the loss of N from agricultural fields to stream corridors (Lowrance *et al.*, 1985; Howarth *et al.*, 2000).

The effectiveness of conservation buffers as a nutrient-management practice can vary significantly. For instance, the route and depth of subsurface water-flow paths though riparian areas can influence nutrient retention. Conservation buffers are most efficient when sheet flow occurs, rather than channelized flow, which often bypasses some of the retention mechanisms. Those areas must be managed carefully to realize their full retention and filtration capabilities.

### *Critical Source-Area Management*

Transport of N and P from agricultural watersheds depends to a large extent upon the coincidence of source (soil, crop, and management) and transport factors (runoff, erosion, and proximity to water course or body). Source factors relate to watershed areas with a high potential to contribute to N and P export. For N, amounts applied in excess of crop requirements can be leached from the soil profile by percolating water. For P, source areas often are spatially confined and limited in extent, generally reflecting soil-P status and fertilizer- and manure-P inputs (Gburek and Sharpley, 1998; Pionke *et al.*, 2000).

Transport factors determine whether nutrient sources translate into nutrient losses. Nitrogen transport from agricultural land generally occurs on a watershed scale. Source factors tend, therefore, to govern the magnitude of N loss, while transport factors dictate the time lag or delay caused by percolation through various soil layers. Nitrogen loss from cropland depends upon the balance between N added (amount, timing, and form of N) and crop removal. The rate of N loss through leaching (transport factor) depends upon soil properties (primarily texture and permeability) and the amount of water available to drain through the soil profile (rainfall and irrigation).

## The Evolution of Phosphorus Indexing

Although many BMPs are available to mitigate nutrient runoff under a variety of site-specific settings, selection and targeting of these practices remains a critical need. Site-risk assessment and P Indexing goes a long way to addressing this need. The site-assessment tool, or P Index, was first proposed in 1993 and eventually adopted into the US Department of Agriculture's Natural Resource Conservation Service (NRCS) Conservation Practice Standard for nutrient management (*i.e.*, the NRCS 590 Standard). The P Index was designed to identify and rank critical source areas of P loss based on site-specific source factors (soil P, rate, method, timing, and type of P applied) and transport factors (runoff, erosion, and proximity to streams) (Lemunyon and Gilbert, 1993). The fundamental advantage of the P Index is to enable targeting of remedial management to critical source areas where high P sources and transport potential coincide (Figure 5).

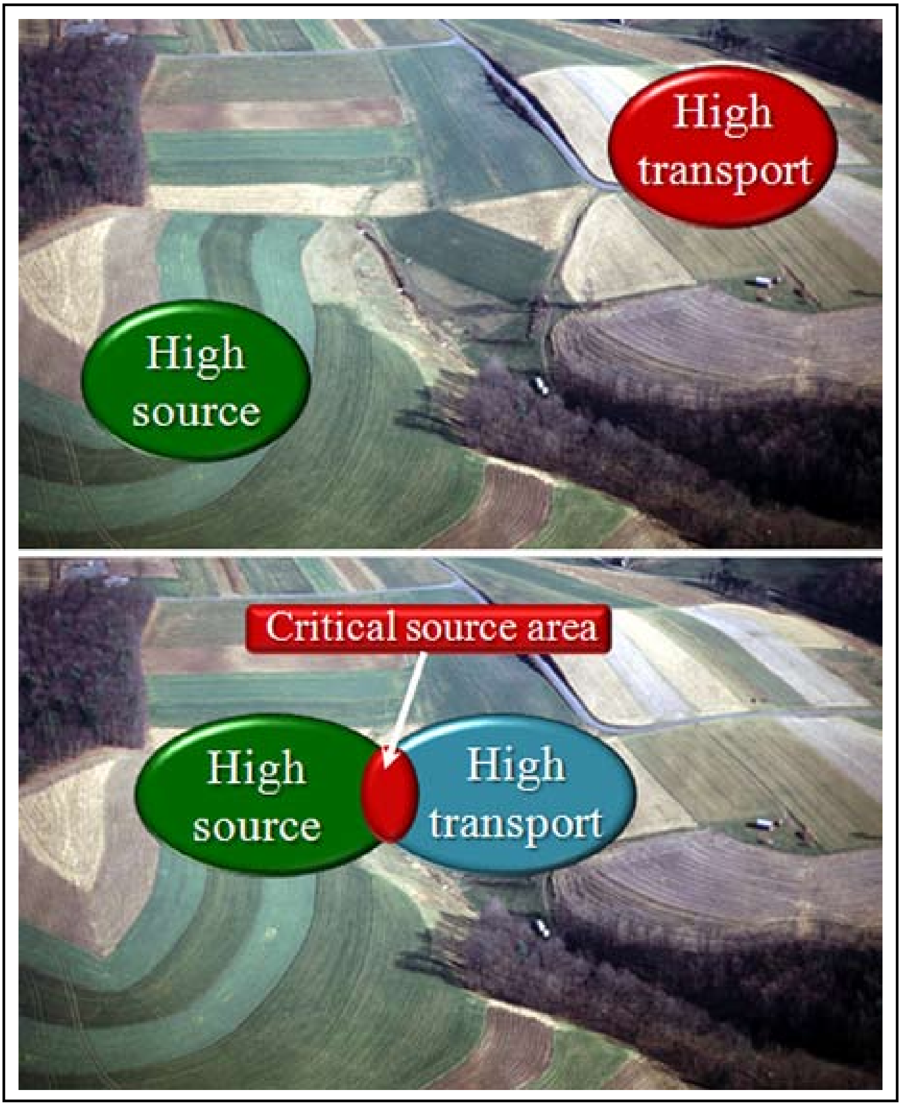



Figure 5. The critical source area concept defining where both high P sources coincide with areas of high transport potential on a landscape delineating high risk areas for remediation efforts.

The scientific basis of P Indices came from research that showed that the majority of the P loss (>80%) originated from only a small proportion of a watershed (<20%) (Pionke *et al.*, 1997; 2000). These critical source areas, as visualized in Figure 5, are essentially P hotspots with active hydrological connectivity by overland flow (Walter *et al.*, 2000; Gburek et al., 2007).

This approach differs profoundly from others that are based solely on soil-P concentration. Although they require more information on site source and transport conditions, P Indices more reliably identify nonpoint sources of agricultural P and provide greater flexibility in remedial options and more cost-effective management recommendations. Currently, 47 US states have adopted the P Index as a site-assessment tool to identify critical source areas and target remedial practices (Sharpley *et al.*, 2003).

The highly significant, positive correlation between soil-test P or degree of P saturation and runoff dissolved P concentration is well established (Vadas *et al.*, 2005) and is frequently used to justify the use of thresholds to limit P application. However, a wealth of scientific evidence is available documenting that, in addition to soil-test P and/or degree of P saturation, P application rate, timing, and method, erosion, runoff, and drainage all influence field-P loss. Use of soil-test P or degree of P saturation alone will not accurately portray a site's risk for P loss because it does not capture the potential for transport potential of a field. If soil-test P is the only assessment used, P runoff and/or leaching losses might be allowed to continue on sites with high P-transport potentials and conversely P application may be restricted although the risk of P loss is low (Figure 6). The data in Figure 6 are from the FD-36 watershed in south-central Pennsylvania (adapted from those presented in Sharpley *et al.*, 2001). Runoff was collected from 2-m$^2$ plots subject to 70 mm hr$^{-1}$ rainfall (to create 30 min of runoff) across the watershed and related to plot Mehlich-3 soil P and soil P saturation of 0- to 5-cm samples collected after rainfall, as well as P-Index ratings determined by the Pennsylvania P Index (Sharpley *et al.*, 2001).

An important lesson from the above analysis is that there were sites with "low" soil-test P and soil-P saturation that had high losses of P due to combinations of factors that include high runoff volumes and/or application of fertilizer or manure. It should be noted that these "low" P sites are above the agronomic response range (*i.e.*, >50 mg P kg$^{-1}$ as Mehlich-3 soil P). On the other hand, there were sites with low P loss but with high soil-test P or soil-P saturation values (Figure 6).

Clearly, consideration of site hydrology is critical for determining P loss (Gburek and Sharpley, 1998). For instance, Buda *et al.* (2009) monitored contour-cropped fields on a Pennsylvania hillslope, where the bottom field possessed the lowest relative soil-test P (roughly two-fold lower than the other fields). Although this bottom field was the only one that did not receive P amendments during the study period, it yielded runoff volumes roughly 50-fold greater than the other fields included in the study. Annual loads of P from this hydrologically active field were >8 kg ha$^{-1}$, in comparison to 1 kg ha$^{-1}$ or less from the other fields. This study highlights the possibility of site hydrology overwhelming source factors and converting a modest source of P into a major P load.

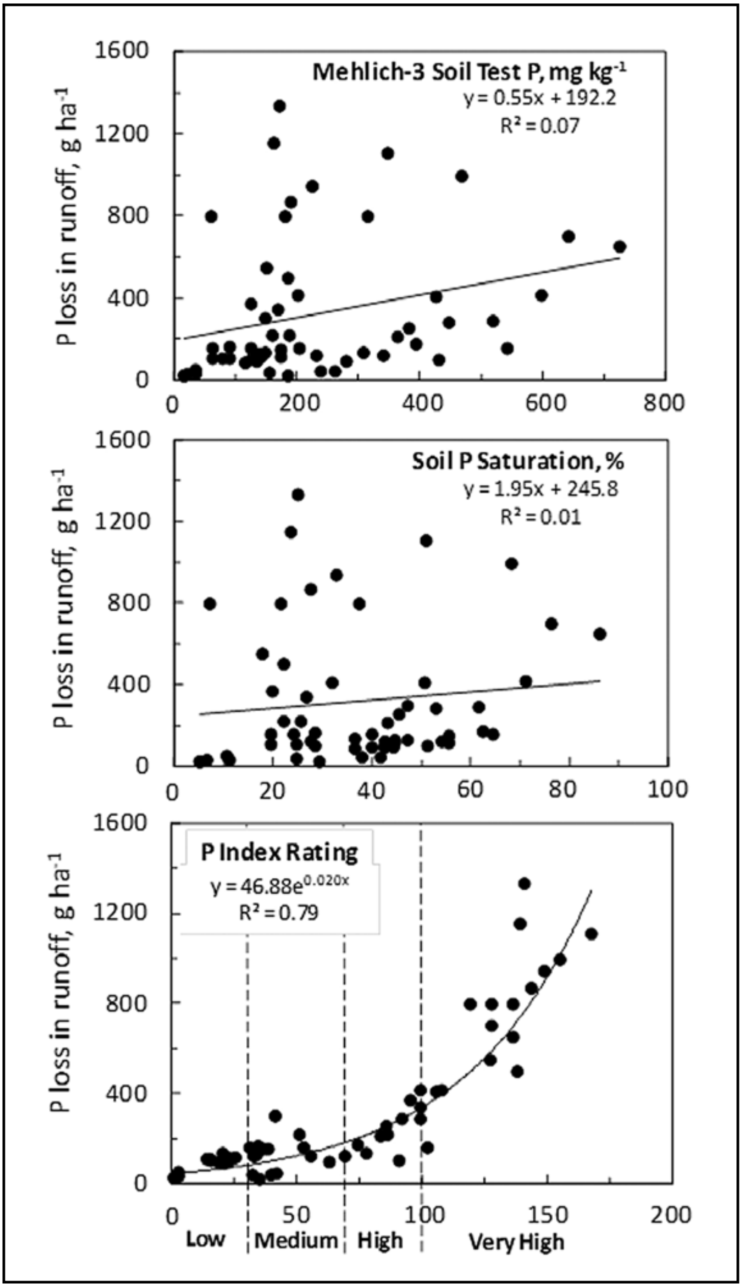



Figure 6. Relationship between the loss of TP in runoff and Mehlich-3 soil test P, soil P saturation, and the Pennsylvania P-Index ratings for the plots in the FD-36 watershed, PA (adapted from Sharpley *et al.*, 2001).

Even in regions where subsurface-flow pathways dominate, areas contributing P to drainage water appear to be restricted to soils with high soil-P saturation and hydrologic connectivity to the drainage network. For example, Schoumans and Breeuwsma (1997) found that soils with high P saturation contributed only 40% of TP load, whereas another 40% came from areas where the soils had only moderate P saturation but some degree of hydrological connectivity with the drainage network.

## Adaptive Management

Several land-management practices and system options are available, which, in and of themselves, can lead to nutrient-loss reductions. To be effective in decreasing nutrient loads, where there is a wide range in production systems, however, there must be careful selection and targeting of conservation practices and management strategies. These practices vary in effectiveness among watersheds and there will be synergistic effects on nutrient-loss reductions, where combinations of these practices can further enhance overall reduction, when appropriately targeted to areas of high nutrient-source availability and those that are hydrologically active. This is the basis for adaptive management of these practices, such that if nutrient-loss reductions are not achieved by implementing nutrient efficiency, edge-of-field buffers or offsite wetlands, then one or all are reassessed and modified.

An adaptive management approach provides an appropriate way for decision makers to deal with the uncertainties inherent in the environmental repercussions of prescribed actions and their influences on water quality at multiple scales. At a basin scale, adaptive management requires measurement of both nutrient loadings and the extent and duration of specific water-quality impairment. Although it will not be possible to relate these changes to specific changes in a basin, these data will provide better understanding of the relationships between nutrients and water-quality impairment. On smaller scales, management actions can be treated as experiments that test hypotheses, answer questions, and thus provide future management guidance. This approach requires that conceptual models are developed and used and relevant data are collected and analyzed to improve understanding of the implications of alternative practices. Research driven by adaptive management is conducted in a framework where the testing of hypotheses and the new knowledge gained is then used to drive management adaptations, new hypotheses and new data gathering on endpoints. Unlike the traditional model of hypothesis-driven research, adaptive management implies coordination with stakeholders and consideration of the economic and technological limitations on management.

A basin-level response to practices cannot be expected to be observed for some time. We need a better understanding of the spatial and temporal aspects of basin-level responses, but must also focus on other scales at which responses can occur in a more timely fashion. This would likely be smaller sub-watershed scales, where local water quality and quantity benefits may become evident more quickly, and which enhance practice adoption.

## Demonstrating the Beneficial Impacts of Agricultural Management on River-Water Quality

Best management practices addressing source controls (*e.g.*, rate, method, and timing of applied P) and transport controls (*e.g.*, conservation tillage, contour plowing, and riparian buffers) have reduced concentrations and loads of P in agricultural runoff both at field and at farm scales (Maguire *et al.*, 2009; Sharpley *et al.*, 2009). The Maumee and Sandusky Rivers (tributaries of Lake Erie, Ohio) exemplify how widespread adoption of conservation tillage can dramatically reduce P loads (Richards *et al.*, 2009). However, as described earlier, a range of factors, including surface soil build up of P increased dissolved P transport (Joosse and Baker, 2011). In general, there has been more limited success in reducing river-water P concentrations and loads at a watershed scale (Sharpley *et al.*, 2009; Reckhow *et al.*, 2011). Also, large-scale initiatives such as the Management Systems Evaluation Areas (MSEA) and Agricultural Systems for Environmental Quality (ASEQ) have revealed some of the difficulties in demonstrating the effectiveness of BMPs at watershed scales (Mulla *et al.*, 2008). These difficulties include multiple and complex P sources, inadequate intensity of BMPs moving to larger spatial scales and the role of long-term re-release of "legacy P" stored within the watershed. As a result of this legacy and variable response times, longer-term monitoring (decadal-scale) will likely be needed to demonstrate the benefits of agricultural management on river-water quality at the wider watershed scale (Gassman *et al.*, 2010).

## Legacies of Past Management

Past land use or land-management activities can lead to a long-term legacy of P in watersheds, stored in surface soils, ditches, riparian zones, wetlands and stream and lake sediments. The stored P can be subsequently re-released as the P-storage capacity gradually becomes saturated, or after a change in land use, land management, or effluent management (Kleinman *et al.*, 2011). Legacy P stores may be widely distributed across the watershed, but the precise locations and impacts are currently poorly understood. The lag times associated with release of P from legacy P stores may help to explain the difficulties in detecting water-quality improvements at a watershed scale (Meals *et al.*, 2010). For example, where soil-test-P levels have risen to more than 10 times crop-sufficiency levels, it can take a decade or more to "draw down" soil-P reserves to levels where dissolved P in runoff is substantially reduced (Sharpley, 2003; Hamilton, 2012).

Beyond the field boundary, legacy and water-quality response times are variable and highly dependent on sediment and water-residence times. For example, the lag time for release of legacy P after point-source mitigation in a small, lowland chalk river (the River Lambourn, UK), was only around 8 months (Jarvie *et al.*, 2006). Impoundments, such as ponds, wetlands, lakes, reservoirs and canals, significantly delay recovery, owing to the longer sediment-retention times (Bosch *et al.*, 2009). The "draw-down" of legacy P in lake sediments, via internal re-cycling, can take years to decades to achieve the required P-reduction goals (Seo, 1999; May *et al.*, 2011).

Legacy P and the associated time lags for recovery, often mask the effectiveness of BMPs on river-water quality at a watershed scale. However, by developing watershed-scale monitoring that identifies local-scale improvements and associated time lags in water quality as they occur, watershed planners can start to better understand and plan nutrient-reduction measures.

## Setting Nutrient Criteria to Manage Ecological Impairment of Rivers

Nutrient criteria are designed to protect water quality for designated uses, which include drinking, contact recreation, and/or ecological quality and biodiversity. Numerical nutrient criteria concentration standards offer regulatory agencies a means to initiate and encourage changes in land use or land management within a watershed. Frequency distributions and stressor-response relationships are two approaches that have been recommended for establishing P criteria (US Environmental Protection Agency, 2000). The frequency-distribution approach involves assessing TP concentrations for either selected "reference" sites or for both reference and potentially impacted rivers over broad spatial and temporal scales (Haggard and Scott 2011). The 75$^{th}$ percentile of TP concentrations in reference rivers, and the 25$^{th}$ percentile of TP concentrations of all rivers covering a broad spatial scale, have been proposed as potential benchmarks for P criteria. The stressor-response approach relies on the relationships between TP (stressor) and various direct and indirect responses of river biological communities such as algal biomass (Smith and Tran, 2010). However, linkages between ecological impairments in rivers and nutrient enrichment are not always well understood (Dodds, 2007).

The frequency-distribution approach assumes that a reference baseline trophic state naturally occurs within a region and that P concentrations need to be reduced to re-establish pre-impacted or pristine "reference" conditions (Soranno *et al.*, 2011). Often, there is a scarcity of data from truly undisturbed, pristine reference sites in many regions (US Environmental Protection Agency, 2010b) and, whilst achieving "pristine" conditions may be a laudable aspiration, it is uncertain whether this can ever be feasible in watersheds where there is agricultural, human population and/or industrial activities. Both the frequency distribution and stressor-response approaches assume that temporal changes in algal growth, at any given river location, will respond to changes in P concentration in direct accordance with spatial patterns in TP-algal response relationships. However, this underlying assumption does not always apply, because relationships between TP and algal biomass are complex. In fact, TP-algal biomass linkages can become decoupled by interactions among many different local environmental factors that influence the accrual or loss of algal biomass in rivers (discussed below).

## Recovery of Aquatic Ecosystems Through P Mitigation

The use of nutrient criteria to manage river eutrophication is based upon an assumption of "smooth reversible ecosystem dynamics" (Dent *et al.*, 2002), that is, simple, predictable ecological recovery will result from the introduction of P-mitigation measures. In some cases, reduced P concentrations have indeed resulted in improved river ecology (Kelly and Wilson, 2004; Bowes *et al.*, 2011a). However, in other cases, even after dramatic reductions in river-water P concentrations have been achieved through P-source mitigation, ecological improvements have not occurred and nuisance algal growth has actually increased (Jarvie *et al.*, 2004; Neal *et al.*, 2010; Bowes *et al.*, 2011b). Algal biomass production can become decoupled from water-column P concentrations, for example: when P concentrations remain above the limiting threshold for algal growth (Bowes *et al.*, 2011b); as a result of luxury uptake during periods of higher P availability; or where high productivity in algal biomass production results in a high supply and turnover rate of P (Dodds, 2003). Algal biomass production is also regulated “top-down” by invertebrate and fish grazers (Kohler *et al.*, 2011). Moreover, *both* N and P can co-limit primary productivity in streams (Dodds and Welch, 2000). Physical factors such as high flow velocities, light availability/shading, temperature, turbidity, channel morphology, and substrate and hydraulic disturbance can also influence accrual of both benthic and phytoplankton biomass (Maret *et al.*, 2010). Also, growing evidence suggests that river-ecosystem recovery is complicated by non-linear responses with hystereses resulting from a range of internal and external feedback mechanisms (Clements *et al.*, 2010).

The River Kennet in southern England is an example where reductions in P concentrations to below nutrient-criteria levels, instead of improving stream ecology, actually resulted in worsening of aquatic ecological status, owing to proliferation of nuisance diatoms (Jarvie et al., 2004). Disturbances to a stressed ecosystem, by introduction of foodweb changes through fish stocking, water abstraction, and changes in flow regime may also contribute to non-linear or hysteretic recovery trajectories. In some cases, the final endpoint may shift or recovery may not occur until P concentrations are reduced far below those concentrations that triggered the original onset of eutrophication. Despite the importance of P for nuisance algal growth in rivers, we cannot always assume that ecological recovery will result from agricultural management to reduce P losses, owing to a range of other controls and feedbacks. Time lags and hystereses may be involved in the recovery path, and we may even have to have to accept that aquatic ecology may get worse before it gets better!

## Balancing Competing Demands

As we move forward with putting our knowledge of agricultural management, water quality and ecologically healthy waters into practice, we will need to provide a balance among competing demands and uses for farm production and designated water uses. The main questions that will need to be answered to provide this balance are:

- *How can we equitably balance demands for restoring impaired aquatic ecosystems with the need to ensure food security and meet demands for increased food production?* Inputs to agriculture are required to achieve and maintain maximum crop (and forage) yields at the level of productivity we expect from our agricultural landscape in today’s world. In fact, inputs will likely have to increase to raise food production needed to feed a rapidly growing and more affluent global population. Further, P is an essential component of animal diets to ensure bone development and reproduction, and dietary feed grains are often supplemented with mineral phosphates. Intensification and decoupling of crop and animal systems and the segregation of livestock farms from arable farms to meet market demands for cheap agricultural grain and protein produce, led to greater inputs of P during the last 50 years. This economically driven intensification leads to large surpluses of P in localized areas that far exceed crop needs. At the same time, we have learned, and have attempted to come to terms with, the fact (with limited success) that P inputs to freshwater systems accelerate eutrophication, which impairs many designated water uses. However, the global dilemma we now face is, how do we raise agricultural production on the same land acreage to feed twice as many, and a generally more affluent population, by 2050?

Clearly, to achieve increased yields and P-use efficiency will require greater, or greater coordinated, recycling of P globally. For instance, efforts need to be focused on how to efficiently use or exploit accumulated soil-P resources by rhizosphere management, *i.e.*, by manipulating rhizosphere chemistry and biology (the thin layer of soil surrounding roots to increase P mobilization and acquisition) and reducing the reliance on chemical fertilizer P. Opportunities include optimization and control of the input of chemical P into soil, use of different plant genotypes, and rhizosphere-management strategies to stimulate P mobilization. Also, P-recycling efforts can provide a major opportunity to better recognise the fertilizer value of manure and to recycle and reuse P from manures and other by-products. Coupled with this, we need to "encourage" more efficient recycling of manure, biosolids, and other by-product nutrients via innovative integration of financial incentives and stricter regulations that could close the P cycle. This will be a fundamental question that needs to be answered in order to meet stricter water-quality standards and nutrient criteria, while still producing cheap food.

- *What mechanisms are available to foster a more open dialogue on uncertainties in the likely outcomes and timescales in use of P-based nutrient management to control eutrophication?* We are dealing with complex systems, the legacy of past land-use practices and recovery pathways that can be long and tortuous. Modern agriculture has developed into very efficient production systems, albeit a one-way transfer from mined areas to grain production and to animal production and human consumption, with a small proportion of P returned to crop-productions areas. Thus, there are large accumulations of P in intensive animal confinement and urban areas. Where P is applied to agricultural land, a portion (~5% to 10%) makes its way to streams, rivers, lakes and oceans. However, a large portion (~50%) is stored within the ecosystem and released slowly to the environment, exacerbated by the problem that there is at least an order of magnitude between optimum levels in soil for crop production (~0.2 mg $L^{-1}$) compared with waters for algal biomass enrichment (~0.02 mg $L^{-1}$). In fact, a large proportion of this is stored in agricultural systems, whereas in urban systems there is much more efficient hydrological connectivity/delivery to surface waters.

Mineral resources are part of our natural capital and economy, but are vulnerable to interruptions of supply. There are many "scare stories" regarding the security of supply of minerals for food security like P. This is a consequence of the exploitation of the "low hanging fruit" of major mineral reserves for much of the developed world. Extracting lower-grade reserves carries both a high energy demand and magnifies environmental impact through enhanced resource dissipation. It is important to recognize that, unlike peak oil, there is no "peak P." What does exist is a complex juxtaposition of risk-factors that govern P supply. These factors are multidimensional (geological, technical, environmental, social, political, and economic), and closing the loop requires navigating all these risks.

- *What sorts of river and rural environments are achievable and affordable, given that for many of our rivers it may not be possible to achieve "pristine" conditions if we want people, farming and economic growth within our watersheds?* It is clear that remediation of nonpoint and point sources in most watersheds can be expensive, even with cost-share and subsidy programs. Upgrading wastewater-treatment plants to meet stricter nutrient criteria can increase costs exponentially, once discharge-consent thresholds have been lowered to below 0.5 mg $L^{-1}$, for example. This has put a burden on many small communities, such as in the Chesapeake Bay Watershed where total maximum daily loads (TMDLs) have predicated point-source reductions. Similarly, conservation practices to minimize nutrient loss (in surface and subsurface flows), required by each Bay State with implementation of Watershed Improvement Plans (WIPs), can be extremely expensive to implement and maintain. Thus, there are numerous sources of technical assistance and financial cost-share and loan programs to help defray the costs of constructing or implementing practices that safeguard soil and water resources. Some of these sources are Conservation Technical Assistance (CTA), Conservation Reserve Program (CRP), Conservation Security Program (CSP), Environmental Quality Incentives Program (EQIP), Small Watershed Dam Restoration (SWDR), Special Water Quality Incentives (SWQI), Wetlands Reserve Program (WRP), and Wildlife Habitat Incentive Program (WHIP).

The amount of federal funds available for the EQIP program for the period 2002–2007 was $5.8 billion, or more than 4.5 times the total spent under the 1996 Farm Bill. Sixty percent of these funds were used to address livestock problems, many of which are nutrient related. Further issues related to whether this program will reach water-quality goals include whether the EQIP funds will be effectively targeted to problem areas and integrated well with other water-quality programs (Clean Water Act's Total Maximum Daily Load program), and if sufficient public and private organizational resources will exist for effective implementation of the program. In 2010, $1.2 billion were available for EQIP, which was a shortfall of $250 million from budgeted amounts. Some watershed-based programs have been established to provide technical assistance and financial support to farmers participating in water-quality-protection programs. Perhaps the most prominent among these is the New York City Watershed Agriculture Program, where savings the city achieved through filtration avoidance have been used to subsidize farmer BMPs at up to 100% cost-share rates in upstate areas that feed the municipal drinking-water reservoirs.

Clearly, with rising costs of water-quality remediation and protection, the question of when “enough is enough” will have to be addressed. For example, the cost of implementing measures to meet a TMDL at the mouth of the Mississippi River to decrease and maintain the hypoxic zone in the Gulf of Mexico to a size of 5,000 $km^2$, will be extremely large. Detailed and realistic cost-benefit analyses will be needed on this and similar waters to answer this fundamental question of what is achievable, affordable, and even desired by the majority of watershed stakeholders.

- *Do we need better convergence between science and public perception in defining what constitutes impaired waters?* The current science focus is on numerical standards of biomass accrual or subtle shifts in algal or macroinvertebrate community structure. However, the general public tends not to be concerned until there is visible impairment or species shifts, such as toxic algae, which result in water-quality problems. One way of bridging this gap may be through exploring ideas and gaining consensus on what constitutes “river health” (*e.g.* Boulton, 1999). Such approaches are helping to bring together ecologists, water-quality scientists, the general public and other watershed stakeholders, through a common goal of achieving healthier and sustainable river environments. “River health” provides a more pluralistic definition, which relies not solely on water quality or ecological criteria, but incorporates wider society values. “River health” also recognizes that rivers are valued for a range of functions, not only as recreation and aesthetic amenities, but for agriculture, industry and to support both urban and rural populations. This highlights potential conflicts between different river uses and the desire to achieve ecosystem structure and function as close to pristine conditions as possible. It also brings challenges about how to best develop simple metrics and tools that incorporate aspects of what society values as healthy river environments alongside more easily-measured chemical, physical, and ecological criteria.
- *Can we implement strategies to move beyond single P-based nutrient criteria and consider other nutrient and pollution controls, together with physical habitat and top-down controls linked to invertebrate and fish interactions to promote more resilient aquatic-ecosystem functioning*? While ecosystem health and aquatic habitat are more fundamental primers of true water-quality status, the use of site factors controlling ecosystem health and functioning adds great complexity to water-quality standards and directives. Numeric nutrient criteria, while simplistic and broad sweeping, are easier to set, implement, and enforce, albeit with limited technical rigor. A compromise approach among various strategies to define critical criteria and conditions leading to use impairment is needed. This should be based on a weight-of-evidence approach, rather than one specific numeric nutrient criterion for a large ecoregion or water system. To be successful, the development and implementation of these tools and strategies will require an honest and forthright two-way dialogue between those developing the foundational science of these

tools and those making and implementing nutrient-management policies. Such dialogue will be essential to limit the softening of technically rigorous and politically difficult approaches to truly reducing excess nutrient loading.

- *Can the principles of adaptive management be used to support more flexible and responsive monitoring, which with stakeholder involvement, evaluates water quality and ecological responses to a range of management options?* Adaptive management implies an understanding that complex problems will require iterative solutions that will be possible only through monitoring, wider community and stakeholder consultation and generation of new knowledge as successive approximations to problem solving are attempted. Stakeholder involvement helps with consideration of the economic and technological limitations on management, focuses attention on where the priorities for remediation lie, and how increasingly squeezed resources might best be allocated. However, perhaps the biggest difficulties for adaptive management are the time lags in water quality and ecological recovery, linked to the legacy of past land-use management and the "re-equilibration" of ecosystems after implementation of management change. These lags in recovery hamper the iterative approach, because they make it difficult to detect whether a management intervention simply has not worked or whether more time (perhaps on a scale of decades) may be needed for improvements to be seen.

## Conclusions

In the past, separate strategies for P and N have been developed and implemented at the farm or watershed scale. Because of differing biology, chemistry and flow pathways of P and N in soil, these narrowly targeted strategies may lead to conflicting or sub-optimal advice. As a result, the prevention of P and N losses from agricultural systems needs to focus on defining, targeting, and remediating source areas of P that combine high soil-P levels with high erosion and surface runoff potentials and source areas of N that coincide with soils of high permeability. Thus, differing levels of management may be appropriate for different areas of a watershed. Overall, inputs in fertilizers and manures should be carefully matched with crop needs over the whole watershed. Short-term remediation of P loss should focus on critical source areas of P export where high soil P, P application, and zones of surface runoff and erosion coincide. However, lasting improvements in water quality can be achieved only by balancing system inputs and outputs of both P and N. Clearly, the management of agricultural nutrients involves a complex suite of options that must be customized to meet site-specific needs that are depicted in Figure 3. Even so, the long-term impacts have been and remain difficult to quantify.

A range of voluntary and regulatory measures can be used to encourage implementation of nutrient-management strategies as part of conservation programs to protect soil and water resources. In general, the success of these measures relates to how well farmers can afford to implement new management strategies and the concomitant level of support or incentives for their adoption. Unfortunately, less attention has been given to mechanisms or programs that support the maintenance of implemented BMPs. Oftentimes, maintenance costs are appreciably greater than implementation costs, particularly as farm labor.

Research that better quantifies the sinks and sources of nutrients as they are transported through a watershed, and the legacies and lags from past land use, will help develop realistic expectations for BMP use and the timescales for aquatic-ecosystem recovery. In addition, continuing educational efforts with the public and farmers regarding the importance and impact of BMPs on environmental quality parameters will be essential to reach environmental goals. In some instances, local or regional governmental controls may be necessary to enhance prompt adoption of practices that will have a positive influence on environmental outcomes.

As we have moved from nutrient management that improves crop production to the environmental-quality arena, we face many challenges in balancing competing demands for protecting and restoring water quality and aquatic ecology, with sustainable and efficient agricultural production. Measures have become more costly to farmers and have raised the old dilemma, "who benefits and who pays?" It is important to recognize that market prices do not always motivate farmers to manage nutrients in an environmentally sustainable way. Consumers can be given a choice about which products they buy, with premiums paid to farmers who provide more environmentally friendly products. But, clearly, current technology and water-quality policy will not permit an unlimited number of animals in a region, or allow production of high-risk crops on land with a high nutrient-loss risk. Relatedly, another important question that should be asked of the public and agricultural communities is: what price are we willing to pay for cheap clean water and low-cost agricultural grains, protein, milk, *etc*?

In some areas, we cannot and should not expect that pristine waters are achievable with ever-increasing population densities and more intensive agricultural production systems to meet demand. The bottom line is that this may require either a reassessment of water-use designations and/or far-reaching societal commitment and support of agricultural system changes.

## References


Bengtson RL *et al.* (1988) The influence of subsurface drainage practices on nitrogen and phosphorus losses in a warm, humid climate. Transactions of the American Society of Agricultural Engineers 31 729–733.

Bosch NS *et al.* (2009) Nutrient fluxes across reaches and impoundments in two southeastern Michigan watersheds. Lake and Reservoir Management 25 389–400. doi: 10.1080/07438140903238674.

Boulton AJ (1999) An overview of river health assessment: philosophies, practice, problems and prognosis. Freshwater Biology 41P 469–479.

Bouwman AF Booij H (1998) Global use and trade of feedstuffs and consequences for the nitrogen cycle. Nutrient Cycling in Agroecosystems 52 261–267.

Bowes MJ *et al.* (2011a) Changes in water quality of the River Frome (UK) from 1965 to 2009: Is phosphorus mitigation finally working? The Science of the Total Environment 409 3418–3430.

Bowes MJ *et al.* (2011b) Nutrient and light limitation of periphyton in the River Thames: implications for catchment management. The Science of the Total Environment doi: 10.1016/j.scitotenv.2011.09.082.

Buda AR *et al.* (2009) Effects of hydrology and field management on phosphorus transport in surface runoff. Journal of Environmental Quality 38 2273–2284.

Burkholder JA Glasgow HB Jr. (1997) *Pfiesteria piscicida* and other *Pfiesteria*-like dinoflagellates: Behavior, impacts, and environmental controls. Limnology and Oceanography 42 1052–1075.

Clements WH *et al.* (2010) Use of ecological thresholds to assess recovery in lotic ecosystems. Journal of the North American Benthological Society 29 1017–1023.

Council of European Communities (2000) Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy. Official Journal L 327, P. 0001-0073 (22/12/2000) http://europa.eu.int/comm/environment/water/water-framework/index_en.html.

Cox FR (1994) Current phosphorus availability indices: Characteristics and shortcomings. In: Soil Testing: Prospects for Improving Nutrient Recommendations, Soil Science Society of America Special Publication No. 40 (Havlin JL *et al.* Eds.) pp. 101–114. Madison: Soil Science Society of America..

Daverede IC *et al.* (2003) Phosphorus runoff: Effect of tillage and soil phosphorus levels. Journal of Environmental Quality 32 1436–1444.

Dent CL *et al.* (2002) Multiple states in river and lake ecosystems. Philosophical Transactions of Royal Society of London Series B–Biological Sciences 357 635–645.

Djodjic F *et al.* (2000) Temporal and spatial variations of phosphorus losses and drainage in a structured clay soil. Water Research 34 1687–1695.

Dodds WK (2003) Misuse of inorganic N and soluble reactive P concentrations to indicate nutrient status of surface waters. Journal of the North American Benthological Society 22 171–181.

Dodds WK (2007) Trophic state, eutrophication and nutrient criteria in streams. Trends in Ecology and Evolution 22 669–676.

Dodds WK Welch EB (2000) Establishing nutrient criteria in streams. Journal of the North American Benthological Society 19 186–196.

Duxbury JM *et al.* (1993) Contributions of agroecosystems to global climate change. In: Agroecosystem Effects in Radiatively Important Trace Gases and Global Climate Change, Special Publication 55 (Harper LA *et al.* Eds.) pp. 1–18. Madison: American Society of Agronomy.

Edwards DR Daniel TC (1993) Drying interval effects on runoff from fescue plots receiving swine manure. Transactions of the American Society of Agricultural Engineers 36 1673–1678.

Fox RH *et al.* (1986) Nitrogen fertilizer source, and method and time of application effects on no-till corn yields and nitrogen uptakes. Agronomy Journal 78 741–746.

Gassman PW *et al.* (2010) Conservation practice establishment in two northeast Iowa watersheds: Strategies, water quality implications, and lessons learned. Journal of Soil and Water Conservation 65 381–392.

Gburek WJ Sharpley AN (1998) Hydrologic controls on phosphorus loss from upland agricultural watersheds. Journal of Environmental Quality 27 267–277.

Gburek WJ *et al.* (2007) Incorporation of variable-source-area hydrology in the Phosphorus Index: A paradigm for improving relevancy of watershed research. In: Proceedings, Second Interagency Conference on Research in the Watersheds (Fowler DL Ed.) pp. 151–160. Washington, DC: US Department of Agriculture. http://naldc.nal.usda.gov/download/45892/PDF.

Groffman PM *et al.* (1992) Nitrate dynamics in riparian forests: Microbial studies. Journal of Environmental Quality 21 666–671.

Haggard BE Scott JT (2011) Water quality standards: Designated uses and numeric criteria development. In: Water Quality Concepts, Sampling, and Analysis (Li Y *et al.* Eds.). Boca Raton: CRC Press.

Hamilton SK (2012) Biogeochemical time lags may delay responses of streams to ecological restoration. Freshwater Biology 57(s1) 43–57. doi:10.1111/j.1365-2427.2011.02685.x

Haygarth PM *et al.* (1998) Phosphorus budgets for two contrasting grassland farming systems in the UK. Soil Use and Management 14 160–167.

Hergert GW (1987) Status of residual nitrate-nitrogen soil tests in the United States of America. In: Soil Testing: Sampling Correlation, Calibration, and Interpretation. Special Publication 21, pp. 73–88. Madison: Soil Science Society of America.

Hilton J *et al.* (2006) How green is my river? A new paradigm of eutrophication in rivers. The Science of the Total Environment 365 66–83.

Holland EA *et al.* (1999) Contemporary and pre-industrial global reactive nitrogen budgets. Biogeochemistry 46(1–3) 7–43.

Howarth RW *et al.* (1996) Regional nitrogen budgets and riverine N & P fluxes for the drainages to the North Atlantic Ocean: Natural and human influences. Biogeochemistry 35 75–139.

Howarth RW (2000) Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution. Washington, DC: National Academies Press.

Jarvie HP *et al.* (2006) Within-river nutrient processing in Chalk streams: The Pang and Lambourn, UK. Journal of Hydrology 330 101–125.

Jarvie HP *et al.* (2004) Assessing changes in phosphorus concentrations in relation to in-stream plant ecology in lowland permeable catchments: bringing ecosystem functioning into water quality monitoring. Water, Air & Soil Pollution: Focus 4 641–655.

Joosse PJ Baker DB (2011) Context for re-evaluating agricultural source phosphorus loadings to the Great Lakes. Canadian Journal of Soil Science 91 317–327.

Kelly MG Wilson S (2004) Effect of phosphorus stripping on water chemistry and diatom ecology in an eastern lowland river. Water Research 38 1559–1567.

Kleinman PJA *et al.* (2005) Effect of cover crops established at time of corn planting on phosphorus runoff from soils before and after dairy manure application. Journal of Soil and Water Conservation 60 311–322.

Kleinman PJA *et al.* (2011) Soil controls of phosphorus in runoff: Management barriers and opportunities. Canadian Journal of Soil Science 91 329–338.

Kohler TJ *et al.* (2011) Nutrient loading and grazing by the minnow Phoxinus erythrogaster shift periphyton abundance and stoichiometry in mesocosms. Freshwater Biology 56 1133–1146. doi: 10.1111/j.1365-2427.2010.02557.x.

KovzeloveCT. *et al.* (2010) Quantification and implications of surplus phosphorus and manure in major animal production regions of Maryland, Pennsylvania, and Virginia. Annapolis: Water Stewardship. http://waterstewardshipinc.org/downloads/P_PAPER_FINAL_2-9-10.pdf

Lemunyon JL Gilbert RG (1993) The concept and need for a phosphorus assessment tool. Journal of Production Agriculture 6 483–486.

Lowrance RR *et al.* (1985) Managing riparian ecosystems to control non-point pollution. Journal of Soil and Water Conservation 40 87–91.

Magdoff FR *et al.* (1984) A soil test for nitrogen availability to corn. Soil Science Society of America Journal 48 1301–1304.

Maguire RO *et al* (2009) Critical evaluation of the implementation of mitigation options for phosphorus from field to catchment scales. Journal of Environmental Quality 38 1989–1997.

Maret TR *et al.* (2010) Influence of environmental factors on biotic responses to nutrient enrichment in agricultural streams. Journal of the American Water Resources Association 46 498–513.

May L *et al.* (2011) Historical changes (1905–2005) in external phosphorus loads in Loch Leven, Scotland, UK. Hydrobiologia doi: 10.1007/s10750-011-0922-y.

Meals, DW *et al.* (2010) Lag time in water quality response to best management practices: A review. Journal of Environmental Quality 39 85–96.

Mueller DH *et al.* (1984) Phosphorus losses as affected by tillage and manure application. Soil Science Society of America Journal 48 901–905.

Mulla DJ *et al.* (2008) Limitations of evaluating the effectiveness of agricultural management practices at reducing nutrient losses to surface waters. In: Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop, pp. 189–212. St. Joseph, MI: American Society of Agricultural and Biological Engineers.

National Research Council (2008) Nutrient Control Actions for Improving Water Quality in the Mississippi River Basin and Northern Gulf of Mexico. Washington, DC: National Academies Press. http://www.nap.edu/catalog/12544.html.

Neal C *et al.* (2010) Declines in phosphorus concentration in the upper River Thames (UK): Links to sewage effluent cleanup and extended end-member mixing analysis. The Science of the Total Environment 408 1315–1330.

Osborn SL *et al.* (2002) Detection of phosphorus and nitrogen deficiencies in corn using spectral radiance measurements. Agronomy Journal 94 1215–1221.

Peterjohn WT Correll DL (1984) Nutrient dynamics in an agricultural watershed: Observations on the role of a riparian forest. Ecology 65 1466–1475.

Pierson ST *et al.*, (2001) Phosphorus and ammonium concentrations in surface runoff from grasslands fertilized with broiler litter. Journal of Environmental Quality 30 1784–1789.

Pierzynski GM Logan TJ (1993) Crop, soil, and management effects on phosphorus soil test levels. Journal of Production Agriculture 6 513–520.

Pionke HB *et al.* (1997) Hydrologic and chemical controls on phosphorus losses from catchments. In: Phosphorus Loss to Water from Agriculture (Tunney H *et al.* Eds.) pp. 225–242. Cambridge, UK: CAB International.

Pionke HB *et al.*. (2000) Critical source area controls on water quality in an agricultural watershed located in the Chesapeake Basin. Ecological Engineering 14 325–335.
Pote DH *et al.* (1996) Relating extractable soil phosphorus to phosphorus losses in runoff. Soil Science Society of America Journal 60 855–859.
Powell JM *et al.* (2001) Dairy diet effects on phosphorus cycles of cropland. Journal of Soil and Water Conservation 56 22–26.
Powell JM *et al.* (2002) Phosphorus feeding and manure nutrient recycling on Wisconsin dairy farms. Nutrient Cycling in Agroecosystems 62 277–286.
Reckhow KH *et al.* (2011) Achieving Nutrient and Sediment Reduction Goals in the Chesapeake Bay: An Evaluation of Program Strategies and Implementation. Washington, DC: National Academies Press.
Richards RP *et al.* (2009) Improved water quality in Ohio tributaries to Lake Erie: A consequence of conservation practices. Journal of Soil and Water Conservation 64 200–211.
Richards RP *et al.* (2010) Unusually large loads in 2007 from the Maumee and Sandusky Rivers, tributaries to Lake Erie. Journal of Soil and Water Conservation 65 450–462.
Schindler DW *et al.* (2008) Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment. Proceedings of the National Academy of Sciences of the USA 105(32) 11254–11258.
Schoumans OF Breeuwsma A (1997) The relation between accumulation and leaching of phosphorus: Laboratory, field and modelling results. In: Phosphorus Loss from Soil to Water (Tunney H *et al.* Eds.) pp. 361–363. Cambridge, UK: CAB International Press..
Seo DI (1999) Analysis of sediment characteristics and total phosphorus models for Shagawa Lake. Journal of Environmental Engineering 125 346–350.
Sharpley AN (1997) Rainfall frequency and nitrogen and phosphorus in runoff from soil amended with poultry litter. Journal of Environmental Quality 26 1127–1132.
Sharpley AN (2003) Soil mixing to reduce surface stratification of phosphorus in manured soils. Journal of Environmental Quality 32 1375–1384.
Sharpley AN (Ed.) (2000) Agriculture and Phosphorus Management: The Chesapeake Bay. Boca Raton: CRC Press.
Sharpley AN *et al.* (2001) Phosphorus loss from land and water: Integrating agricultural and environmental management. Plant and Soil 237 287–307.
Sharpley AN *et al.* (2003) Development of Phosphorus Indices for nutrient management planning strategies in the U.S. Journal of Soil and Water Conservation 58 137–152.
Sharpley AN *et al.* (2007) Overcoming the challenges of phosphorus-based management in poultry farming. Journal of Soil and Water Conservation 62 375–389.
Sharpley AN *et al.* (2009) Evaluating the success of phosphorus management from field to watershed. Journal of Environmental Quality 38 1981–1988.
Sharpley AN Rekolainen S (1997) Phosphorus in agriculture and its environmental implications. In: Phosphorus Loss from Soil to Water (Tunney H *et al.* Eds.) pp. 1–54. Cambridge, UK: CAB International Press.

Sharpley AN Smith SJ (1994) Wheat tillage and water quality in the Southern Plains. Soil Tillage Research 30 33–38.
Sharpley AN Syers JK (1979) Loss of nitrogen and phosphorus in tile drainage as influenced by urea application and grazing animals. New Zealand Journal of Agricultural Research 22 127–131.
Sims JT *et al.* (1998) Phosphorus losses in agricultural drainage: Historical perspective and current research. Journal of Environmental Quality 27 277–293.
Sims JT Kleinman PJA (2005) Managing agricultural phosphorus for environmental protection. In: Phosphorus; Agriculture and the Environment (Sims JT Sharpley AN Eds.) pp. 1021–1068. Madison: American Society of Agronomy.
Sims JT Sharpley AN (Eds.) (2005) Phosphorus: Agriculture and the Environment. Madison: American Society of Agronomy.
Smith AJ Tran CP (2010) A weight-of-evidence approach to define nutrient criteria protective of aquatic life in large rivers. Journal of the North American Benthological Society 29 875–891.
Soranno PA *et al.* (2011) Quantifying regional reference conditions for freshwater ecosystem management: A comparison of approaches and future research needs. Lake Reservoir Management 27 138–148.
Torbert HA *et al.* (2002) Relationship of soil test phosphorus and sampling depth to runoff phosphorus in calcareous and noncalcareous soils. Journal of Environmental Quality 31 1380–1387.
US Environmental Protection Agency (1996) Environmental Indicators of Water Quality in the United States. EPA 841-R-96-002. USEPA, Office of Water (4503F). Washington, DC: US Government Printing Office.
US Environmental Protection Agency (2000) Ecoregional Nutrient Criteria Documents: Rivers and Streams. Washington, DC: U.S. Environmental Protection Agency. http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/rivers/index.html.
US Environmental Protection Agency (2002) Nutrient Water Quality Criteria, Summary Table for the Nutrient Criteria Documents. http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/.
US Environmental Protection Agency (2010a) Guidance for Federal Land Management in the Chesapeake Bay Watershed. Chapter 2: Agriculture. EPA841-R-10-002. US EPA, Nonpoint Source Pollution, Office of Wetlands, Oceans, and Watersheds. http://www.epa.gov/nps/chesbay502/pdf/chesbay_chap02.pdf
US Environmental Protection Agency (2010b) Review of Empirical Approaches for Nutrient Criteria Development. EPA Scientific Advisory Board. http://yosemite.epa.gov/sab/sabproduct.nsf/95eac6037dbee075852573a00075f732/E0937EC14CB3F2B85257713004BED5F/$File/EPA-SAB-10-006-unsigned.pdf.
Uusi-Kämppä JB *et al.* (2000) Buffer zones and constructed wetlands as filters for agricultural phosphorus. Journal of Environmental Quality 29 151–158.
Vadas PA *et al.* (2005) Relating soil phosphorus to dissolved phosphorus in runoff: A single extraction coefficient for water quality modeling. Journal of Environmental Quality 34 572–580.

Varvel GE *et al.* (1997) Ability for in-season correction of nitrogen deficiency in corn using chlorophyll meters. Soil Science Society of America Journal 61 1233–1239.

Walter MT *et al* (2000) Hydrologically sensitive areas: Variable source area hydrology implications for water quality risk assessment. Journal of Soil and Water Conservation 55(3) 277–284.

Westerman PW*, et al.* (1983) Erosion of soil and poultry manure—a laboratory study. Transactions of the American Society of Agricultural Engineers 26 1070–1078, 1084.

Withers PJA *et al.* (2003) Incidental phosphorus losses—are they significant and can they be predicted? Journal of Plant Nutrition and Soil Science 166 459–468.

**ANDREW SHARPLEY** is a professor in the Department of Crop, Soil and Environmental Sciences, Division of Agriculture University of Arkansas in Fayetteville. He received degrees from the University of North Wales and Massey University, New Zealand. His research investigates the fate of phosphorus in soil-plant-water systems in relation to soil productivity and the effects of agricultural management on water quality. He also evaluates the role of stream and river sediments in modifying phosphorus transport and response of receiving lakes and reservoirs. Dr. Sharpley developed decision-making tools for agricultural field staff to identify sensitive areas of the landscape and to target management alternatives and remedial measures that have reduced the risk of nutrient loss from farms. He works closely with producers, farmers, and action agencies, stressing the dissemination and application of his research findings. He is director of the multi-stakeholder Arkansas Discovery Farm Program to document and demonstrate the benefits of farm conservation measures that protect water quality and promote sustainability. In 2008, he was inducted into the USDA-ARS Hall of Fame and, in 2011, received the Hugh Hammond Bennett Award from the Soil and Water Conservation Society.

**HELEN JARVIE** is a visiting distinguished professor in the Department of Crop Soil and Environmental Sciences at the University of Arkansas. Dr. Jarvie is visiting Arkansas from the United Kingdom, where she is a principal scientist in Environmental Chemistry at the UK Centre for Ecology and Hydrology in Wallingford. Her research addresses the need to protect water resources from excessive nutrients (nitrogen and phosphorus), which can cause nuisance algal growth and degradation in water quality. She has been awarded a Fulbright Fellowship and an OECD Fellowship to undertake a 12-month sabbatical at the University of Arkansas. Her research project investigates the retention, cycling and legacy of phosphorus and nitrogen in watersheds and the implications for water-quality management and aquatic-ecosystem sustainability.

# *Viewpoints and Changing Practices of Arkansas Rice Farmers*

Ray Vester
*E&M Farms*
*Stuttgart, Arkansas*

ray_vester@hotmail.com

When people ask me what I do, I tell them I'm just a farmer. Sometimes they ask, "Well, why do you say that?" Most of us who farm—I would say 99%—do so because that's what we want to do. We don't want to deal with all the problems of regulations, of politics or of subsidies. We want to till the soil and plant a crop and watch it grow and harvest it. But, we've come far from that today. I found the following words this past week in a magazine:

> *Agriculture is the foundation and cornerstone of civilization. Without a dependable and safe food system there could never have been the opportunity for any other professions or pursuits to evolve or to even flourish. We seem to have, as a society, forgotten this. Consecutive generations of my family have farmed this country since before its founding. We are strong-willed—a nice way of saying stubborn—independent, resourceful people…These pioneers were at the same time establishing communities as they created their farms.*

I wish I had the ability to have written that. Where we fail in agriculture is we don't have a spokesman who is nationally accepted and listened to, to tell the story of agriculture. It was written by an Arkansas man who lives in Little Rock, P. Allen Smith. He is on television quite a bit with shows about gardening and lifestyle.

I grew up on the Grand Prairie of Arkansas, which is located between the White and Arkansas Rivers. It was a tall-grass prairie. My father said that, when he was a small boy—he was born in 1907—in late spring when the prairie grass was fully grown, a man riding across it on a horse could be seen only from his shoulders up. The cash crop was hay. It was shipped by rail from points in Stuttgart and other sidings along the St. Louis-Southwestern Railroad known as the cotton belt.

## Rice Arrives in Arkansas

In the 1900s, rice was planted in the Carlisle area, north of Stuttgart on the western side of the Grand Prairie. It was successful. My grandfather raised the first field of rice on our family farm in 1908, and it has been part of the Grand Prairie ever since. It is a good crop for the Grand Prairie because of two things. A good supply of water is available from the Alluvial Aquifer, which ranges from 130 to 180 feet deep. And a hard pan holds the floodwater by preventing percolation.

Cultivation of rice slowly but surely grew from that point into the 1950s, becoming increasingly important. The main sources of income were rice as a cash crop and cattle. They raised rice almost continuously. They would pasture or summer kill the field and about every third year the field was raised in rice. Water tables held up fairly well. The Grand Prairie, where rice-production was concentrated, starts just below Des Arc, Arkansas, and runs 70 miles to the south-east between the two rivers, to Gillett, Arkansas, with a maximum width of 30 miles.

In the 1950s and 1960s, many new wells were sunk. Recharge for the Alluvial Aquifer comes mainly from the White River, and, in the south, from the Arkansas River. The water table began to drop slowly as more water was taken out each year to irrigate crops. Around 1958, cattle prices fell and beef production decreased. Soybeans were introduced onto the prairie as a rotational crop. Tyson Foods built a processing plant in 1960 in Stuttgart, and soybeans became an alternative crop in rotation with rice. Soybean was the minor crop, cultivated for extra income without irrigation.

## Management

At that time, rice was normally planted from April 10 to May 20 and was harvested from September 20 to October 20, a 150-day growing season. It was estimated then that rice used about 36 acre inches of water. I would say that it was probably closer to 40 acre inches at that time, because water did two things. It kept the aquatic crop alive and it helped prevent infestation of grassy weeds. Grass-only herbicides were not available. We had herbicides for broadleaf weeds, albeit not many, so the fields were flooded when the weeds were small but then because of the alkaline condition of the Alluvial water the soil pH kept rising and the rice would get sickly; we'd drain and reflood and drain and reflood until the rice became sufficiently well developed to withstand the alkaline conditions. Then came economic considerations; there was a desire to irrigate not only rice but also soybean to increase yields. Agriculture is kind of a reverse business. We farmers buy everything at retail and sell it at wholesale. And we are takers of prices, not staters of prices. In agriculture, as supply increases and prices drop—a normal economic condition—to survive we must produce more at a lower price.

So, the demand for water also applied to soybean, which started to pull heavily on the aquifer. A couple of things happened. Some in the late 1950s and early 1960s began putting down deep wells into the Sparta Aquifer, which is anywhere between 450 to 750 feet deep. Memphis, Tennessee, Greenville, Mississippi, and most of the larger towns in the delta get their drinking water from the Sparta Aquifer. At the same time, a balancing influence came in: research at a rice experiment station in Stuttgart started developing fast-maturing varieties. These are still planted from April 10 to May 20, but they are harvested from August 20 to about September 15. With the growing season shorter by 30 days, the amount of water used is reduced, and we have herbicides now to take care of the grass problem. But we still have water-related issues. Not only does the Alluvial Aquifer keep dropping; so does the Sparta Aquifer.

## Addressing Aquifer Depletion

In 1972, we farmers were encouraged to grow rice from fence row to fence row. Production increased and, in some years in Arkansas, 1.8 million acres were devoted to rice production with 48–52% of all the rice raised in the United States. More wells were poked into the ground, some between the Grand Prairie and the rivers, cutting off aquifer recharge. The Alluvial Aquifer, instead of being 80 feet deep when I was a young man, now is closer to 120 feet deep. The Sparta Aquifer is being similarly depleted.

In the late 1950s, exploitation of surface water began. Large reservoirs were built, not only for irrigation, but also for commercial hunting. Although that has been helpful, aquifer depletion is still occurring. Underground pipe linkages were started in the late 1950s and early 1960s, first with transite pipe, 10, 12 and as large as 15 inches in diameter. Now most of that pipe is PVC, at 12 inches in diameter. On my family farm, which encompasses 1,160 acres, we have installed 18,000 feet of underground pipe since 1961. It closes open canals where evaporation is high, where seepage and leakage from those canals is severe, and where continuous maintenance is needed. It takes irrigation water underground into a closed system with conservation benefits.

We now use Poly-pipe, which is rolled out into the field. Holes provide row irrigation. It was first used on the prairie mainly for irrigating soybean and corn, but now, through research at our experiment station, they have discovered that if you roll Poly-pipe down the hill through a rice field across the levees, you poke multiple holes at each levee and flood the entire field at one time, evaporation and other water losses are reduced by maybe 15%.

We use landforming, probably more so off the prairie than on the prairie. The problem with landforming on the Grand Prairie is that the topsoil, at best, averages 4 inches thick. To level the field, the top soil is removed and stockpiled and then reapplied after leveling; if the soil is not replaced, cropping is impossible. In the other areas of Arkansas in the Delta where rice is now raised, top soils are 3- to 4-feet deep, so they just cut it level. A zero grade requires less water to achieve flooding.

In the past 10 years, we have developed tailwater recovery systems, which are installed at the bottom ends of large fields' drainage areas; irrigation water runs from fields into pit reservoirs. Each is basically a contour hole in the ground and the water is pumped back to the top of the field and reused.

We now have row rice, which is planted like soybeans. Poly-pipe is laid between the rows, as with soybeans. To hold the cost down, at the bottom of the field a tailwater recovery trench is installed so that excess water can be recirculated.

Center-pivot irrigation is being found to be a viable option for some situations. The rice is watered exactly like corn or soybeans. Surge valves haven't been used much in Arkansas, but they are another option for water conservation. And we have cell-phone applications; without driving to a well to shut it off or start it up, it can be done by telephone.

All of these technologies can help improve water sustainability. However, not all of these approaches work for every farmer. Our goal is to bring understanding to the farmer of what these technologies can contribute to their individual farming operations.

## Priorities

### *Household*

What water issues do farmers face? They are the same as those faced by everyone. The first water issue we face is human consumption. I don't know if many farmers would admit it, but they understand that the number-one need for water in this country is for drinking, cooking, bathing, and general household use. I don't include watering the lawn in that. Common Bermuda grass will survive the worst drought and green up after a half inch of rain. So, I don't consider lawn irrigation to be important. But, certainly, human consumption is the number-one water-use issue we face in this country.

### *Industry*

In Arkansas, water is an industrial issue. We have a huge paper-mill industry in Pine Bluff that takes an enormous amount of water every day, every night, from numerous deep wells in the Sparta Aquifer. It's treated and released and goes downstream. Farmers who operate below Pine Bluff are happy because they have a continuous source of surface water for irrigation. But it is damaging to the Sparta Aquifer. Since the establishment of the Arkansas River navigation system, the level of the Arkansas River is held constant at all times. Water taken from the Arkansas River for industrial use is purified, and reinjected into the river with very little loss.

### *Agriculture*

The third issue we have, of course, is agricultural water. In my personal opinion I think it should be number two, not industry, but I'm not paid by industry; other people have other views. Our biggest issue in agricultural water in Arkansas right now is too much and too little. Farms 20 miles from where I live have been totally inundated by flooding from the White River. This year, those same farms are extremely dry. Water in agricultural situations is hard to plan for. The average annual state rainfall is about 48 inches, an abundant amount. Much of it runs off into the Mississippi River and needs to be captured and stored. We are slowly developing that capability.

To grow crops and feed this country, water is a critical issue. We have to convince farmers who have abundant water to use water-saving devices. Some farmers with access to abundant ground- and surface-water are less than frugal. If you have plenty of disposable income you are comfortable with buying most anything, whereas if your disposable income is limited you are more careful with how you spend it. We, as farmers, need to make this point to agricultural producers in Arkansas: just because you have abundant water doesn't mean you are entitled to use it wastefully. Our challenge as agricultural leaders is to bring this knowledge to the farming community, to do it from a grass-roots level, not from a government level—to impart understanding of what we can do to raise the same crops with less water and less wastefulness. It is key for continued success in row-crop production in Arkansas.

**RAY VESTER** is a fourth-generation rice farmer on the Grand Prairie of Arkansas near the town of Stuttgart. He attended the University of Arkansas, Fayetteville, majoring in accounting. He is active in other aspects of agriculture, including as a member of the USA Rice Federation as chairman of their environmental regulatory subcommittee. He also serves on the Federation biotechnology task force and the sustainability task force. Recently, he completed a two-year term on the Farm Ranch and Rural Community committee, which advises the EPA. He has served the state of Arkansas on the Arkansas State Plant Board for the past 14 years as rice-producer representative. Mr.Vester is also a member of the Arkansas Department of Agriculture advisory board and is active in his community. He has served for 24 years on the board of directors of Producers Rice Mill, Inc., a farmer-owned cooperative comprising 2,500 members. And he is a member of the board of directors of the Farmers and Merchants Bank, a community bank serving the Grand Prairie. He is married to Debra, has two grown children, a daughter Jennifer and a son Cody, and two grandsons.

# *Developments in Water Management and Policy*

Q&A[1]

Moderator: Andy Pereira
*University of Arkansas*
*Fayetteville, Arkansas*

Thomas Redick (Global Environmental Ethics Counsel, Clayton): Dr. Moore, the Gulf Restoration Network and a bunch of NGOs filed a lawsuit in Louisiana earlier this year saying the whole Mississippi TMDL[2] should be litigated into numeric limits just like they did in Florida recently to save that part of the world. So, we now have a 600-pound gorilla of litigation sitting in the middle of Mississippi Basin. Is that going to influence more limits? More trading? Will there be a boost to move this kind of program into other parts of the Mississippi Basin?

Richard Moore: I've been tracking this problem over the last 5 years pretty much. The idea of numeric criteria for watersheds has been promised for Ohio. I talked to Ohio EPA people a couple, 3 and 4 years ago and they said that it would be imposed on Ohio next spring or next fall. It's tied up in litigation. If numeric criteria are imposed on Ohio then we would have nitrogen limits probably 3 milligrams per liter, or as with water-treatment plants sometimes 1 milligram per liter. Three would be huge. On phosphorus, what they are talking about is taking it from 1 milligram per liter down to maybe 0.5. So, in Ohio it is much different, comparing the Ohio River Basin to the Lake Erie Basin, many of the water-treatment plants in the Lake Erie Basin are actually lower, so there is a different history of their regulations. With the Farm Bureau, there's a lot of litigation right now regarding even the ideal TMDLs. TMDLs are created by modeling too. There's been a lot of debate about how accurate the model has been.

[1]Some of the audiorecording, from which this written record was prepared, was of poor quality, rendering it impossible to accurately represent dialogue. Every effort has been made to provide a faithful transcription.
[2]Total maximum daily load.

Hank Venema (International Institute for Sustainable Development, Winnipeg): Dr. Sharpley—a fantastic presentation. Just building on the points that you made that hydrology can overwhelm the system, that we are seeing this rapid uptake of tile drainage and no-till as well, it strikes me that there is a role for hydraulic storage in the system, that you need that buffering capacity. One of the assertions that we're making is that it actually would be acceptable to landowners if it wasn't a dead loss. If that land is taken out and put into hydraulic storage it would be a biomass-for-bioremediation area. You can get a zero-input biomass crop off there to offset the land taken out of production. Given your emphasis on the fact that hydrology can overwhelm all of our best intentions, do you regard that as a viable component here?

Andrew Sharpley: Yes I do. People are looking at enhanced wetlands, whether that is just to store nutrients or also to store water. In your area, that has been more critical because you can store water for later use when you need it. There's a double benefit. So yes, that is critical. I don't want to make the point that tile drainage and conservation tillage are bad. They are not. We need to think about adjusting management on implementation. We have to use tile drains, but we have to consider the hydrology and manage the nutrients we are using on that land a little differently from when it wasn't tile drained. But—storage of water temporarily for reuse or for mitigation—yes.

Bill McCutchen (Texas A&M University, College Station): Mr. Vester, you served on the EPA Advisory Board.

Ray Vester: Yes sir.

McCutchen: We've heard a lot about EPA regulations. With your experience and stature, will you share your feelings about the regulations that are being imposed and are they fair?

Vester: I served on that committee for a 2-year term with Jennie Popp, who is here. We made some great progress. When you serve on that advisory board you have a specific item that you are appointed to address. And we did it in a very good manner and I think we had a good response. For the last 8 or 9 years, I have been chair of the USA Rice Federation Environmental Regulatory Committee. EPA is not particularly my friend. I get along with them. I visit them every year. My personal opinion is that the problem in EPA is—first of all—we have people regulating industry who know nothing about the industry, particularly *vis-a-vis* agriculture and probably any other thing that they regulate. They don't understand what we do. They don't know what we do. Those in leadership positions don't care what we do. They are there for a purpose and with an agenda. Our committee dealt with water quality. Those with great writing skills wrote a paper with advice from some of us who just talked. We understand that regulations are often needed, based on sound science. I think with some EPA decisions, some of their models, aren't based on sound science. We had a very strong science group on this committee of 29 who made that very clear. It was the opinion of this committee—and also my opinion from my experience with the rice industry—that you regulate from the community up, not from the top down. It's not easier to do, but it's more palatable to those whom you regulate. It takes leadership at the community level. As I said earlier, those who just want to be farmers, they can't just be farmers. You have to take the time to get involved at the grass-roots level to bring change. I was very impressed with Ohio's plan—what was accomplished. That made me feel very good: it can work. We sat in committee groups from this advisory committee and we had EPA staffers from different regions who sat in the peanut gallery and listened, and they would chuckle when we talked about what we thought ought to happen because they weren't interested in that. But, for industry's sake, for agriculture's, for the community's, I think the best plan is to do it from the ground up. If you get the people who are going to be regulated on board, if you get community leaders, if you get the leading agricultural people—the farmers who are the leaders in the community—on board, I think it's an addressable thing that you can accomplish. But we have to do it with sound science. Water-quality issues—I know it's coming down the pike, like a snowball headed you know where, because there's a demand, there's a lawsuit. We have to have information first. I know Arkansas is gathering information now because EPA has no information. Instead of assumptions, we have to have sound science. We have to have realistic numbers. We heard it this morning from Dr. Sharpley and others, of what we need to do and how we need to do it, but we have to be proactive. We as farmers, we as scientists, we as industry people, we have to be the ones who lead it.

Jozef Kokini (University of Illinois, Urbana): Mr. Vester, you are one of the few speakers that has actually talked about industrial uses of water. You talked about the paper-pulp industry in the state of Arkansas. We know the food industry consumes a lot of water. The ethanol industry uses a lot of water. So does the oil industry and many others. The statistics suggest that about 80% of the water being used around the world is actually used by agriculture, and I wonder what your thoughts are about the ratio of water that is being used by industry and the water-contamination issues that come from its utilization by industry.

Vester: I know that the fraction of agricultural use of water directly for crop production isn't that high of a percentage, but, even so, that percentage can be lowered and we can still do a quality job of production agriculture. We have waste. We have technology that people don't tend to want to use because it's new. Farmers are hard to get to change, okay? Just as industry is. And there has to be an effort on all fronts to change the pattern of what we do to adopt best practices. It may not be the simplest and it might not be the quickest, but what's best for the sustainability of crop production, for industry, and human consumption, I think that has to be at our forefront. Whatever it takes us to do—and I desire that it not be done by regulation. If you can do it through your agencies, through groups like this, I think you are going to have more success.

Audience Member: A question for Helen Jarvie. I'm curious about your perspective on the UK and EU versus US law, and implementation of policies. One perspective I've had is EU and UK laws work better than a lot of US policy because you don't have unfunded mandated problems. In the US a lot of law is passed without the funding to support that law. So, I'm curious: in your time here in the States what is your perspective of how we do things versus how you do things?

Helen Jarvie: From a water-quality perspective, there is a fundamental difference in approach in Europe. Our water law is subsumed within something called the Water Framework Directive, which has a strong ecological driver. So, the requirement is for the Member States in Europe to achieve good ecological status in our water bodies by 2015. Individual Member States are given quite a degree of freedom in how they go about defining the measures they enact to achieve that good ecological status. Essentially what the Water Framework did was to shift the emphasis in Europe from chemical criteria to biological criteria, and for the UK that was a significant shift in approach. Our water laws are now driving us towards ecological indicators. I think I mentioned that the UK has gone down the route of using diatom indices as a measure of ecological status. That's for convenience and those diatom indices are geared toward critical threshold phosphorus concentrations. But the difference is it's nutrient criteria, it's chemical criteria and total maximum daily loads, that are the drivers of change in water quality and water law. I'm not so familiar with this kind of legislation; perhaps one of the other panelists can help on the US side of things.

Audience Member: Identified by several of you were disconnects in the system. I think Helen identified the disconnect between our understanding of the nature of the legacy of nutrients for example, and the kind of project work we do that's short term whereas it can take a long time to have an impact. And the policy folks are saying, "Tell me something now. I want to know that what you did had some effect." Is there an example of a fix for that disconnect—any mechanism to give us hope that we're going to solve that disconnect?

Richard Moore: This may be a transition from what was just said, but I think that biological criteria are perhaps the best indicators. In the US most of the state EPA's are reliant upon the chemical criteria, which provide data more quickly. Biological criteria are better longer-term indicators.

Andrew Sharpley: I was recently on an NRC panel looking at tracking and accountability within the Chesapeake Bay Program; how successful has that been? We struggled as a group to find successes and I think that they are not at the Chesapeake Bay or the Gulf of Mexico scale. You have to go back to smaller scale and there are examples: Spring Creek within the Chesapeake Bay. We find success stories at a smaller scale; maybe some sea grasses are coming back. That's probably where the focus should go to demonstrate that some of these things do work—like Helen was talking about between where the change has been and the water-body has responded. Don't focus on the large water body, but go back in scale.

Moore: To piggy-back on that—in the case of the Lake Erie algal bloom, a recent development is looking at the algal levels within the streams and rivers that go into the lake, rather than looking at Lake Erie as a whole. Looking at the smaller unit is more effective. I also want to say that Ohio EPA's surface-water division takes a more biological approach than most other state EPAs. It's common to hear them say that biological trumps chemical.

Deanna Osmond: EPA recognizes this and that's why they started the 319 national monitoring program protocol using paired watersheds, because they knew that if they got into smaller areas with a paired watershed approach they could show change much more quickly. Recently, I was at a meeting where the Oklahoma folks talked about successfully using paired watershed designs to implement conservation practices and actually show water-quality change. The small design is the way we are going to have to go to show change.

Audience Member: Further to the question on disconnects—we have multiple different ideas on what are the best management practices to implement. On a large scale or in terms of multiple different point sources, what resources or incentives might be needed for implementation? As you have alluded to, often there is a disconnect between what the farmer is doing and what needs to be done.

Osmond: We are struggling with this question because we recognize—or at least I recognize—that federal resources are dwindling and the federal resources we have are not available to do this. We are going to have to be creative and it's going to have to be a federal, state and local initiative with the private sector, including the farmers. Unless we all decide that this is a priority and work together, there aren't enough resources to fix it.

Vester: Another thing is we talk about solving problems black and white and, when it comes to agriculture, nothing is black and white. I've farmed as an adult for 44 years, but my first job on the farm was when I was 6 years of age, punching wire through a stationary hay bailer. I worked with my dad everyday on the farm that I wasn't in school, so I've seen this for 60 years and in that time no two years were alike. There's been no two things—in putting in a crop—that worked exactly the same as it did the year before. There always are differences and change. When you attack a problem on the farm, it's not black and white, it's gray. You hope that the farmer is getting to the point of controlling the nutrients. It may not be exactly the way it's formulated, but he has to do the things that the weather allows him to do, and that his situation allows him to do.

Sharpley: You are right, it does cost a lot of money and, a lot of times, implementation is only the beginning of it. Fencing, for example, costs a lot to maintain time-wise; there's a hidden cost. Efforts like "green" labeling denoting environmental stewardship—increasing prices by just a few cents—don't work unless everybody is invested, because the people who are driving it tend to buy the cheapest carton of milk and the cheapest cut of meat. I think it has been more successful in Europe. I notice when I go back to the UK that there is a greater awareness of labeling and people look at the sources of what they buy. There is a different approach, but it has been tough to get the public to pay for some of the services they are getting.

Jarvie: Something I have noticed in the UK, where there's been a series of farming catastrophes, is much more awareness about buying local produce and Freedom Foods and the like.

Moore: With regard to problems with budget, there's a lot of potential for cutting costs. We make stream measurements in the lab to fractions of a unit whereas with nitrate, for example, we want to know if the value is 8 or 10. Colorimetric assays could be done at the local community level by collecting water samples. If the local community embraces its own watershed, many inexpensive ways of cleaning it up are available.

Ralph Hardy (National Agricultural Biotechnology Council, Ithaca): What sort of benefit would there be from phytase-enriched feeds, for example, to reduce the necessary phosphate input thereby reducing phosphate in the manure? What about nitrification inhibitors, so you keep more of the nitrogen in the manure in the urea or ammonia state so you don't have the nitrates that will run off in tile drains and so on? What about leguminous cover crops? In terms of improving water quality, is there opportunity to integrate back into the areas you've been talking about or don't you see opportunity?

Sharpley: Definitely there is, yes. I mentioned cover crops, which are gaining wide acceptance. New plants are being looked at as cover crops that farmers could get some cash from. There is intercropping. I think phytase is used widely in the Bay Watershed; others here probably have more experience, but I think it was initially used as a cost-cutting measure because it reduced the need for costly calcium phosphate in feed, but it had the benefit of reducing the excretion of P quite dramatically. That's a win-win because it reduces feed costs and, at the same time, has an environmental benefit.

Osmond: All of these things are regional. A group of us in the southeast and south just looked at some of these products that you were talking about, and found that nitrification inhibitors actually didn't change the fate of nitrogen. Growing cotton in the south, we can't get our cover crop in early enough to make it have any value. A lot of these conservation practices have to be examined in the agro-ecological system that they are being placed in.

Moore: That is an issue that is going to come up with climate change as well in the sense of many genotypes have been selected as longer-season varieties, whereas by having a longer season you are more susceptible to the perturbations—ups and downs—in climate. Shorter-season varieties may help us through climate change as well as provide opportunities for cover crops. The same thing happens in Ohio: a lot of times we run out of season so we don't have time to put in a cover crop.

David Benfield (Ohio State University, Wooster): We are all taking responsibility for looking at water sustainability in agriculture and you have mentioned conservation practices related to that. We are trying to get the message out about being good stewards of the land as well as of water. But does the urban environment play a role in this, outside of agriculture, in terms of phosphorus and so forth?

Jarvie: I'm from a very densely populated little island, Great Britain, and, in our watersheds, urban influences are significant, particularly wastewater point sources. Very often, as you are scaling up to the watershed level the role of agriculture gets subsumed within a big point-source signal. It's different here but, for our watersheds, tackling point sources has been most important. By introducing better tertiary treatment facilities we've been able to dramatically reduce very quickly the phosphorus concentrations in our rivers. We still have a way to go because we have a very dispersed rural population and small, rural wastewater treatment plants are a big issue. I'm not sure that they are so much of an issue here, but, of course, the economies of scale are such that it's much more effective to target the big wastewater-treatment works and yet we end up with an agricultural watershed that does still have big point-source influences.

Vester: If I remember correctly from my 2 years on the EPA advisory committee, 25% of nutrients come from storm water. If you think we in agriculture put a lot of fertilizer on our fields, it's amazing what people put on their yards. Also, they put chemicals on that I have to have a restricted-use pesticide permit to buy. So, there is definitely a problem there that is not being addressed—25% of the problem.

Jarvie: This also goes back to the issue of hydrology. The hydrological connectivity of those urban sources to the stream network is efficient because you have paved surfaces, concrete, tarmac surfaces and a very efficient drainage network. Certainly in the UK, sustainable urban drainage systems are a big issue in terms of trying to promote retention ponds and to delay the delivery of that urban storm water into the river network.

Moore: During the low-flow season in the summer, the city of Columbus uses almost half the water coming down the Scioto River. The largest user of that water is Anheuser Busch. To do their upgrades in the city they have to worry about effects on the price of water. They don't want Anheuser Busch to go to another city, so they want to keep the price of water down. All of these things make it a very complex system.

## CHANGING ROLE OF AGRICULTURE IN ENVIRONMENTAL AND CONSUMER ISSUES

# *An Introduction to the Sustainability Consortium*

Sarah Lewis
*University of Arkansas*
*Fayetteville, Arkansas*

SLewis@walton.uark.edu

I am with the Food, Beverage and Agriculture Working Group of the Sustainability Consortium (TSC), the intent of which is to help businesses focus on issues that really matter using techniques that really matter, to get the most "bang for the buck." We communicate that message across a common platform so that, no matter where you are in the world, the conversations are similar. Of course, regional differences prevail, but means of communication are harmonized.

More and more demands are being made on our natural resources, not just because of increasing population, but also because lifestyles are changing. People are consuming more. How do we address these increasing demands? The Sustainability Consortium's objective is to improve decision making for product sustainability throughout the product life cycle.

There is increasing understanding within the consumer-products industry of impacts and issues involved in achieving sustainability. Underpinned by many types of programs and initiatives and tools, global, federal and state regulations, and NGO expectations, companies are trying to understand how to harmonize this information to inform their decisions and develop best practices consistent with other similar companies. This process is based on science that is open and transparent and continuously improving. The vision is to drive product innovation with continuous improvement in sustainability. The mission is to design and implement credible, transparent and scalable science-based measurements and reporting systems accessible for all producers, retailers and users of consumer products.

Translating TSC's mission into impact requires:

- Using a multi-stakeholder approach…
- …to create practical measurement tools…
- …that enable proactive innovation in sustainability…
- …and unlocks value in the supply chain.

Another issue is unlocking the added value that should come with sustainability; how does an organization communicate the innovative strategies inherent in its products? For the multi-stakeholder approach, we work with academic institutions, corporations and non-profit organizations. We are, essentially, a convener of information and a driver helping to communicate product sustainability. We focus on credibility, drawing on information—including information on water—generated by leading universities and NGOs that use a science-based approach to identify areas of adverse impact in the supply chain.

## TSC Structure

Across the value chain, our membership[1] includes many of the world's most recognized companies, representing $1.5 trillion in revenue, and many different processors and manufacturers. As stated, producer organizations also are involved, NGOs and academic organizations; some are research partners and some participate in advisory roles. The University of Arkansas and Arizona State University have administrative responsibilities. We also have offices at Wageningen University, in the Netherlands, and in Santiago, Chile. We are a global organization with a global perspective, at the same time communicating the need for flexibility at the regional level.

There are seven Sector Working Groups and two Consortium Working Groups within TSC. The former comprise 90 of the largest organizations working together on sector-specific issues:

- Electronics
- Food, Beverage and Agriculture
- Home and Personal Care
- Paper
- Packaging
- Retail
- Toys

And the latter comprise corporate members, non-profit organizations, government agencies and academic institutions:

- Consumer Science
- Measurement Science

[1]http://www.sustainabilityconsortium.org/members/.

We develop tools for application within these industries. I lead the effort within the Food, Beverage and Agriculture sector.

## Main Deliverable

The main deliverable is the development of sustainability measurements and reporting systems, which first require gaining understanding of the key issues. Key issues for water in Arkansas have been mentioned; however, they are likely to be applicable elsewhere. Groundwater depletion and compromised surface-water quality are common global issues. As an organization, from the basic understanding of the key issues, we develop scientifically supported strategies for use by clients. The information is provided in a dossier with 1- to 2-page document as a category sustainability profile that summarizes the environmental and social hotspots—and improvement opportunities—for a product. For instance, water emerges as an environmental hotspot in coffee production; we provide scientifically based strategies to facilitate addressing that hotspot. We may communicate additional issues resulting from consumer observations. Some companies use the scientific data to educate consumers in order to reverse any inaccurate perceptions.

The next stage in the development of the sustainability measurement and reporting tool is to have a more quantitative approach. As a collective we want to design a baseline model, which is a life-cycle assessment model that permits input of quantitative data, *e.g.* gallons of water or kilowatt hours of energy. We are in the process of developing that.

Again, we collect the information in a dossier and create a category sustainability profile, and the next step is the development of key performance indicators. Let's say that a hotspot for grain production involves irrigation and water use (which, in fact, is the case). Water would be included in the list of hotspots in the life cycle for production of packaged cereal. Accordingly, there would be an improvement opportunity and mention may be made of a recommendation from the National Resources Conservation Service (NRCS) or other agency of a strategy commonly used for improving water-use efficiency in irrigation. (Our members are adamant about the use of the word "efficiency" *vis-à-vis* water; availability and efficiency of use need to be considered separately.) Based on this information we are developing questions for generation of a database, so that companies can go to one place to access a survey. The questions will be relevant, in this case, to packaged cereal. Accordingly, it would include queries about grains, questions about manufacturing, retail, use patterns and end of life; all aspects of the life cycle of a packaged cereal.

The Sustainability Consortium's measurement and reporting system reveals value in the supply chain. Improved transparency of reporting is helping to reduce complexity, thus saving costs throughout the supply chain. Standardization of metrics enables buyers and suppliers to work together on the same environmental and social goals. And reduction in costs and in the complexity of sustainability research and reporting allows companies to tackle hotspots faster and more efficiently. In the case of packaged cereal, suppliers and buyers become aware of the impact of water and can use that information as a tool to improve efficiency in the supply chain.

## Organizations Collaborating with TSC: Examples

### *Walmart*

Walmart is incorporating category sustainability profiles and key performance indicators in its merchandizing. They are creating "scorecards" for their suppliers—science-based standard metrics that provide an "index" of a product's sustainability. The scorecards are based on hotspots and improvement opportunities developed and summarized in TSC'S category sustainability profiles.

### *Unilever*

The potential of TSC's tools to engage and educate consumers on product sustainability is recognized by Unilever:

> *The scientific basis of TSC's work helps us focus on activities that matter and distinguish us from other companies. We've identified opportunities and impact… It's not only about how we manufacture it, but also how a consumer uses it. TSC's approach provides the first step for companies to drive consumer engagement.*

Unilever sells many hundreds of products. They can't afford to make full life-cycle assessments of all of them, therefore quick spot analyses of their product categories allows them to focus their resources on hotspots. Water is an ingredient, and a potential hotspot, in all of their products.

### *Kimberly-Clark*

The potential to apply TSC tools across a number of business functions has been identified by Kimberly-Clark, *e.g.* evaluating the sustainability of input materials, ensuring that new products are more sustainable than existing ones, utilizing a single reporting system with all buyers, and reducing sustainability investments by leveraging TSC.

### *P&G*

Proctor and Gamble sees TSC as a catalyst for innovation and collaboration among stakeholders to drive change. They recognized that the use of cold-water formula in laundry detergent is a way to minimize energy consumption. This approach has been shared within TSC as a potential way to minimize energy use.

### *Tesco*

Tesco is planning to use the information in the sustainability measurement reporting system. They seek harmonization of standards, so they are asking the same questions of all their suppliers. Feedback varies with the source, water-scarcity issues in that location, and so on.

### *Dell*

Dell is engaging retail partners, and utilizing the TSC hotspot approach:

*. . . to focus our efforts towards more sustainable solutions. We are starting to work with LCD and other suppliers to better understand their footprints. TSC research gave use more confidence to ask better questions in a standardized way. We can now share our laptop data across other products, such as displays, to identify improvement opportunities.*

### *Mars*

The petcare/confectionary/food giant is moving from measuring to innovation:

> *We want to put all of our effort into improving the supply chain and not into creating the measurement system. . . TSC allows us to be economically efficient—we don't have to spend all our resources on the tape measure.*

### *Henkel*

Henkel's sustainability goal is a three-fold increase in eco-efficiency by 2030:

> *The future of the industry and society is in sustainable consumption. TSC has an important role to play.*

### *WWF*

The World Wildlife Fund engages with TSC to create and refine its tools, ensuring a holistic view of hotspots along the value chain. In turn WWF strengthens the TSC process by:

- Active participation in creating TSC products
  - 235 product-specific comments for 50 dossiers
- Inclusion of broad commodity challenges into hotspot analyses, including
  - Deforestation, biodiversity, climate change, water risk, land use/competition and soil impacts
- Complementing TSC product-category methodology with other assessment methods

## Key Issue: Water

In the dossier containing the relevant information and the category sustainability profile (Figure 1), what are some of the key issues regarding water, that we see across our products, specific to agriculture? The dossier is a collection of evidence gathered from literature, models and subject-matter interviews; it provides transparency and credibility. The category sustainability profile is a synthesis and categorization of information found in the dossier that provides awareness of the most relevant and actionable issues and opportunities. And the key performance indicators are metrics used to record organizational progress on issues and opportunities described in the category sustainability profile; these metrics facilitate performance tracking and communication of progress. What is happening in the scientific community related to packaged cereal or beef or milk or coffee? We collect that information in the dossier and then summarize it to reveal the most scientifically supported issues.

Figure 2 shows the products we are focused on: beef, beer, bread, cotton, packaged cereal, milk, farmed salmon and wine. Grains are included because various types are inputs into several of these products. Water plays an integral part in all of these products. Our knowledge base, contained in the dossiers, reveals that some water issues apply across agriculture, whereas some are unique to specific agricultural systems. Also, some are post-agricultural water issues.

Life-cycle issues that apply across agriculture include:

- Depletion of groundwater and rivers by irrigation
- Fertilizer runoff causing eutrophication of nearby surface waters
- Pesticides, herbicides and defoliants washing into water bodies
- Emissions through fertilizer production and fuel use on the farm causing formation of acid rain
- Poor land management leading to soil loss through erosion and sediment accumulation in streams, rivers and lakes
- Irrigation causing salination of soil

Life-cycle issues that apply in specific situations include:

- Damming and rerouting of natural waters to provide irrigation
- Alteration of water temperature and aquatic biota by flooding fields for crop production
- Improper management of manure, washing pathogens into waterways
- Erosion of soil resulting from livestock traffic, inducing sediment accumulation in streams, rivers and lakes
- Accumulation of livestock-administered antibiotics in aquatic environments

And post-agricultural life-cycle issues include:

- Discharge of organic and other waste compounds in wastewater flows
- Incorporation of scarce water into products
- Gaseous emissions during manufacturing that cause formation of acid rain
- Consumption of water during biofuel generation

These are the key issues—hotspots—that are related to water; some of them are more strongly supported by scientific data than others, but it is important to recognize attendant improvement opportunities. For example, with regard to farmed salmon, the following hotspots imply approaches for amelioration:

- Antibiotics applied to curb disease negatively affect non-target species
- Chemicals to prevent parasite infestations harm non-target invertebrates
- Release of unconsumed fish food and wastes induces eutrophication in surrounding waters

These key issues apply specifically to water. We also examine across-the-board impacts of categories such as energy, land use, biodiversity, and social issues to develop key performance indicators.

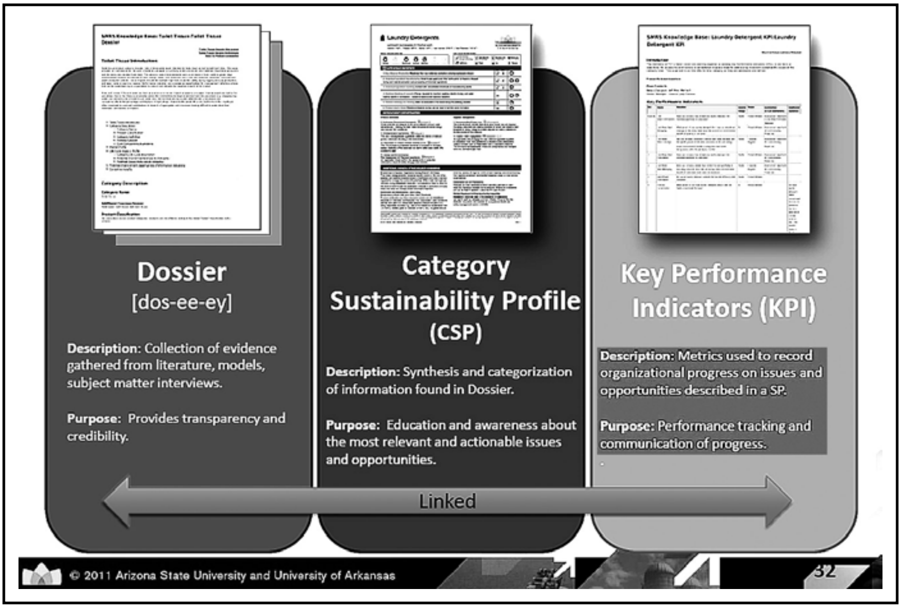



Figure 1. Knowledge products.


Figure 2. The Sustainability Consortium: Food, Beverage and Agriculture sector products.

TSC leverages existing data to identify knowledge gaps and, thus, develop questions as key performance indicators of opportunities for improvement across a product's life cycle. As far as water is concerned, scientifically based examples of key performance indicators that suggest solutions may be:

- Does your farm (or your supplier's farm) have a riparian buffer in place?
- Has your facility adopted a wastewater-management plan?
- Are you keeping an inventory of your water use?

We are working with Marty Matlock (University of Arkansas, Fayetteville) on developing a strategy for capturing regional water risk, to integrate geography into the category sustainability profile. On a 1- to 2-page web document, we envision a link that shows where in the world there are water-scarcity issues, with a drop-down menu that provides science-based strategies for amelioration. This tool will help buyers at Walmart, Mars, Disney, McDonald's, *etc.*, make their conversations more legitimate and scientifically focused. As new studies are published, they can be included.

The objective of the project with Dr. Matlock is to understand the significance of existing water indices. Different indices are based on different methodologies, scales and metrics. His team scanned indices globally with the intent of creating a common metric to help understand the impacts of water in specific regions. In all of the studies consulted available water was addressed (Figure 3), whereas two studies failed to address water requirements, and all but two studies failed to address water seasonality, *etc*.

The data in Figure 3 show relevant tools for possible application across the supply chain. Dr. Matlock took the six indices listed in Figure 3 and created a consolidated index by creating a 0–1 scale for each index range, adding up the outcomes and dividing by the total (Figure 4). We intend to use this to help inform our US members on how to measure water-use efficiency in their practices. Eventually they will be able to say, "I'm in this region and this is the water scarcity here, therefore these are the strategies I will use."

| Water Index | Available Water | Environmental Water Requirements | Water Use or Demand | Return Flows | Physical or Economic Factors | Seasonality | Global Spatial Scale |
|---|---|---|---|---|---|---|---|
| Water Supply Stress Indicator (Sun, McNulty, 2008) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ |
| Human Water Security Threat (Vorosmarty, 2010) | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ |
| Blue Water Scarcity (Hoekstra, 2011) | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✓ |
| Environmental Water Scarcity (Smakhtin, 2005) | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✓ |
| Water Scarcity Index (Pfister, 2009) | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ✓ |
| Mean Annual Relative Water Stress (Alcamo, 2000) | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ✓ |

Figure 3. Variability in water indices.

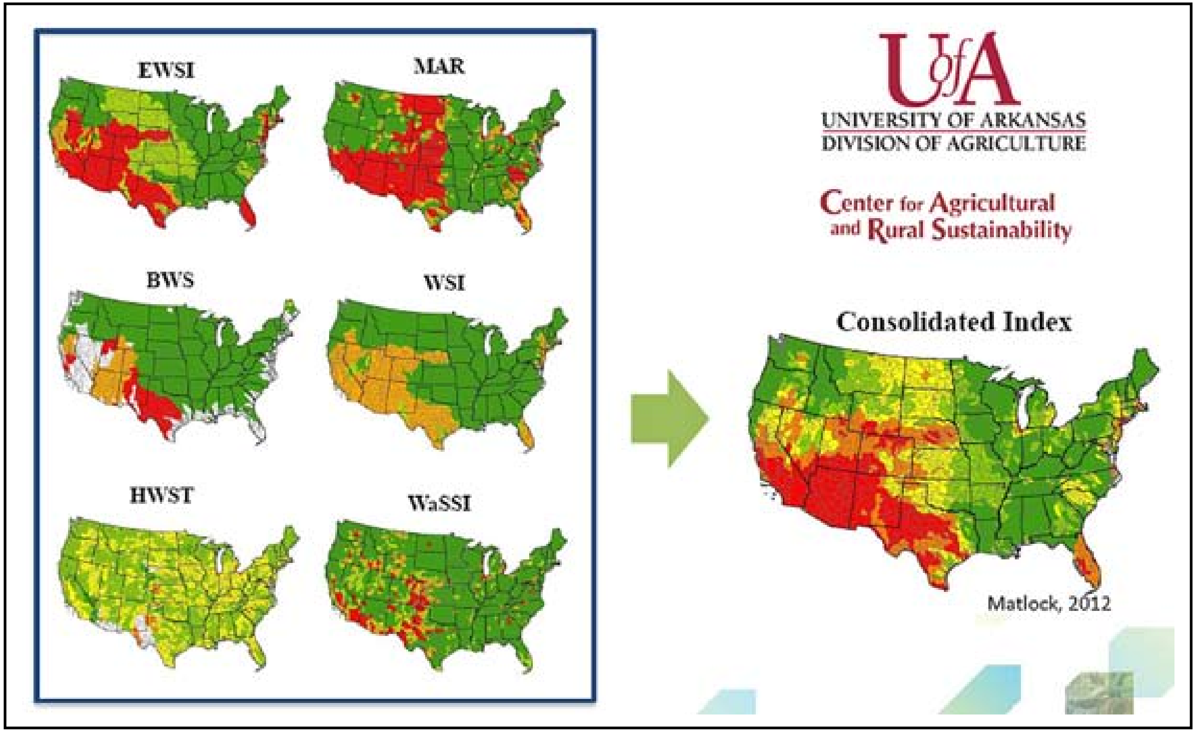



Figure 4. Finding consensus in water indices.
(See Figure 3 and pp. 162 and 163 for explanations of abbreviations.)

**SARAH LEWIS** holds a PhD in environmental dynamics and an MA in French from the University of Arkansas. She received her BS in biology and French secondary education from the University of Nebraska at Lincoln. Dr. Lewis is passionate about identifying and working through challenges at the interface of humans and the environment. Her work with The Sustainability Consortium at the University of Arkansas, Fayetteville, focuses on managing research projects and member relationships within the food, beverage, and agricultural industries in order to develop the Sustainability Measurement and Reporting System. An award-winning educator, she is an adjunct professor of environmental sociology at the University of Arkansas at Little Rock, and is the founder and president of EcoExplique, a consultancy focused on educating communities about ecological economics. An active member of her community, she serves as an elected official on the Fayetteville City Council.

# *Water Conservation Planning: How a Systems Approach to Irrigation Promotes Sustainable Water Use*

Michael E. Sullivan and Walter M. Delp
*Natural Resources Conservation Service*
*Little Rock, Arkansas*

michael.sullivan@ar.usda.gov

By 2050 there will be 9 billion people on this planet, representing a need to increase food production by 70%. How can we meet that demand for food without damaging the environment? For if we meet the food need in an environmentally unsound manner, then it will not be sustainable. This is the challenge for today as we plan for tomorrow.

I (MES) lead the Natural Resources Conservation Service (NRCS) in Arkansas. A federal agency within USDA, NRCS was born during the dust bowls of the 1930s when our mission was to conserve our nation's soils. We have been very effective in this role. Between 1982 and 2007, soil erosion on US cropland decreased 43%. Water erosion (sheet and rill[1]) on cropland in 2007 declined from 1.68 billion tons per year to 960 million tons per year, and erosion due to wind declined from 1.38 billion tons per year to 765 million tons per year (US Department of Agriculture, 2007). Water-erosion rates on cropland dropped from 4.0 tons per acre per year in 1982 to 2.7 tons per acre per year in 2007. Wind-erosion rates dropped from 3.3 to 2.1 tons per acre per year for the same time period. Declines in soil-erosion rates have moderated somewhat since 1997, but the general downward trend in both water and wind erosion continued through 2007.

Since the inception of the NRCS, our focus has expanded to include nine major resource concerns, which include not only soil erosion, but also soil condition, water quantity, water quality, air quality, plant condition, fish and wildlife, domestic animals,

---

[1]Sheet erosion is the planar removal of surface soil by the action of either raindrop splash, shallow flows of surface of water, or even by wind. Rill erosion is usually linked with sheet (water driven) erosion as the shallow flows of water driving sheet erosion tend to coalesce and thus increase both in velocity and scouring capacity.

and energy. In 1994, our name was changed from the US Soil Conservation Service to better reflect our expanded conservation roles. We are a unique agency in that we work on private lands with private land owners. Our mission statement is "Helping People Help the Land," which we accomplish by addressing the resource concerns of landowners throughout the United States.

In Arkansas, we work with a multitude of partners including the Arkansas Natural Resources Commission, University of Arkansas Extension, and the Arkansas Association of Conservation Districts. Locally we have 62 Field Service Centers that have responsibilities for all 72 counties in the state. The staff usually consists of a district conservationist and likely a soil conservationist and, in some cases, a soil-conservation technician. In addition to our Field Service Centers, we have specialists who can provide more detailed support at various levels.

## Water Needs in Arkansas

Only 3% of the earth's water is freshwater, upon which there are various demands. Worldwide, agriculture uses approximately 70% of the freshwater (Steduto *et al.*, 2012). In the United States, Arkansas ranks in the top five for irrigation-water withdrawals (Figure 1) (United States Geologic Survey, undated). Of the water used in Arkansas, agriculture accounts for 76% (United States Geologic Survey, undated). However, Arkansas is a water-rich state; water availability and sustainability are the important issues.

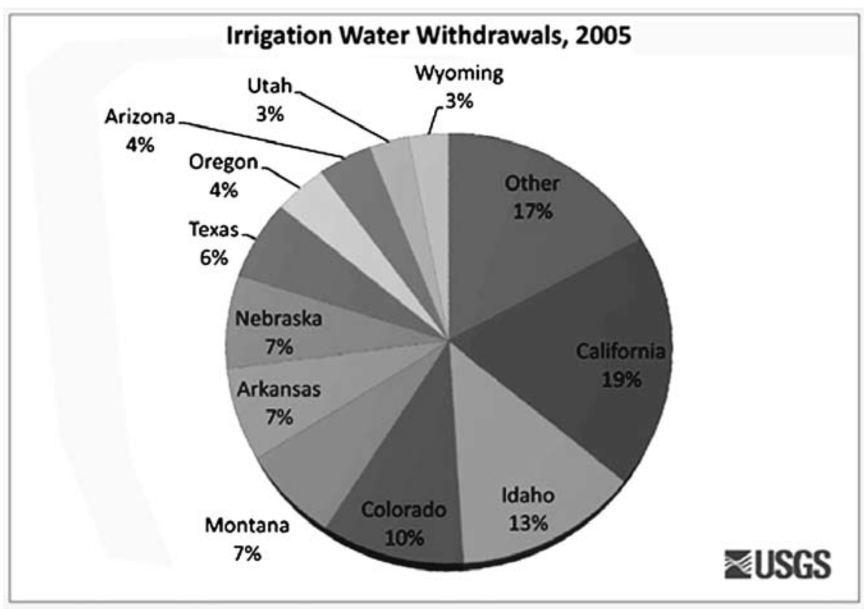



Figure 1. Irrigation-water use by state.

According to the Arkansas Legislative Policy on the State Water Plan:

> *15-22-201. Declaration of policy.*
>
> *(a) It is in the best interest of the people of the State of Arkansas to have a water policy that recognizes the vital importance of water to the prosperity and health of both people and their natural surroundings.*
>
> *(b) Preserving water of a sufficient quality and quantity will allow Arkansas to be known both as a natural state and a land of opportunity where agriculture, industry, tourism, and recreation will remain strong for future generations.*
>
> *(c) It is declared to be the policy of the State of Arkansas to encourage best management practices and reliable data to provide scientific methods for managing and conserving water for future use in recognition of the facts that:*
>
> *(1) Arkansas has annual rainfall providing surplus surface water for the use of persons in this state, while continuing to provide water for wildlife habitat, recreation, industry, agriculture, and commerce;*
>
> *(2) In many instances much of this surplus water is now underutilized;*
>
> *(3) The groundwater supplies of the state are being used at a rate that will result in valuable water aquifers being destroyed, harming both the general public and the private property rights of those owning property in this state; and*
>
> *(4) Surface water and ground water supplies must be managed together for maximum effect.*
>
> *(d) It is declared to be the purpose of this subchapter to permit and regulate the construction of facilities to use surplus surface water in order to, without limitation:*
>
> *(1) Protect critical groundwater supplies that are a significant source of the drinking water supply for thousands of people in Arkansas;*
>
> *(2) Protect the rights of all persons equitably and reasonably interested in the use and disposition of water;*
>
> *(3) Maintain healthy in-stream flows for all streams and rivers;*
>
> *(4) Prevent harmful overflows and flooding; and*
>
> *(5) Conserve the natural resources of the State of Arkansas.*

The majority of irrigation water use is, and has always been, groundwater. Wells have been used in irrigation since the early 1900s. Groundwater levels have been documented as in decline since the late 1920s. Arkansas uses 7.2 billion gallons per day, equivalent to 10,000 Olympic-sized swimming pools daily. This water comes from one primary aquifer

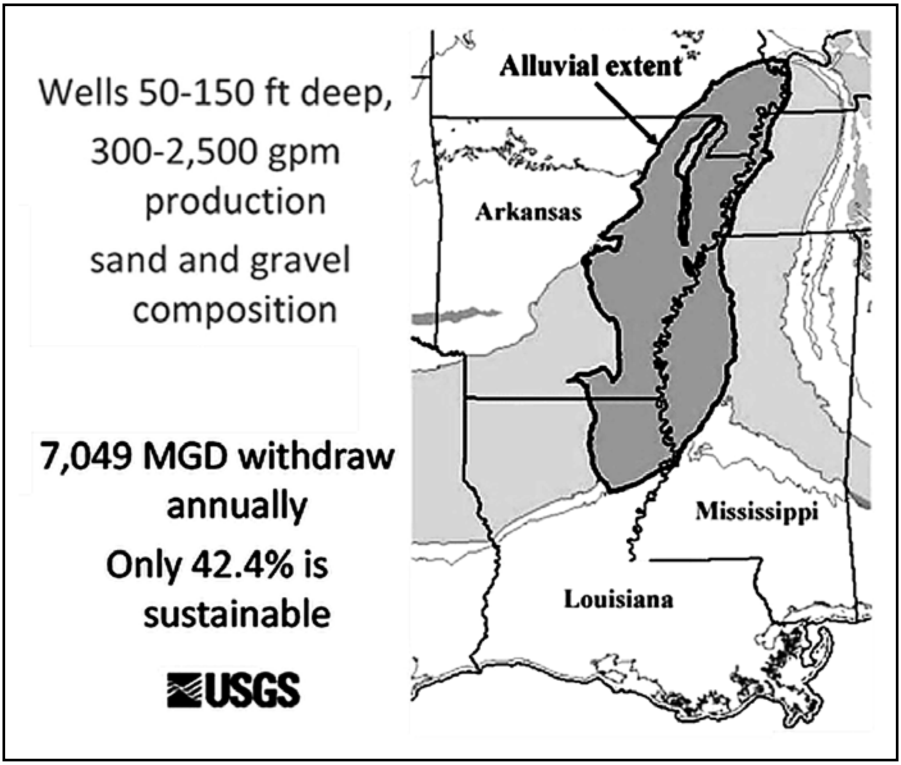



Figure 2. Mississippi River Alluvial Aquifer.

and one secondary aquifer. The Alluvial Aquifer, mostly recharged from the Mississippi, White, Arkansas and other major rivers, does not provide high-quality drinking water and supplies wells that are generally 50- to 150-feet deep. The secondary aquifer, the Sparta Aquifer, is below the Alluvial Aquifer and is a source of high-quality municipal and industrial water,

In Arkansas, groundwater levels are declining in response to continued withdrawals, at rates that are not sustainable. Based on 2008 water-use data, only 43% of the current withdrawal from the Alluvial Aquifer is sustainable. Ninety-six percent of the ground-water pumped from the Alluvial Aquifer is used for agriculture. At these pumping rates, water-level declines and adverse impacts on the state's groundwater system will continue.

The Arkansas Natural Resources Commission's (ANRC) "Arkansas Ground-Water Protection and Management Report for 2010" documents areas where excessive withdrawals have led to cones of depression of the groundwater level. Without an adequate solution to the region's groundwater problems, studies predict that the Alluvial Aquifer will be commercially useless by 2015. Figure 3 (Figure 5 in the ANRC Report) shows current depths to water.

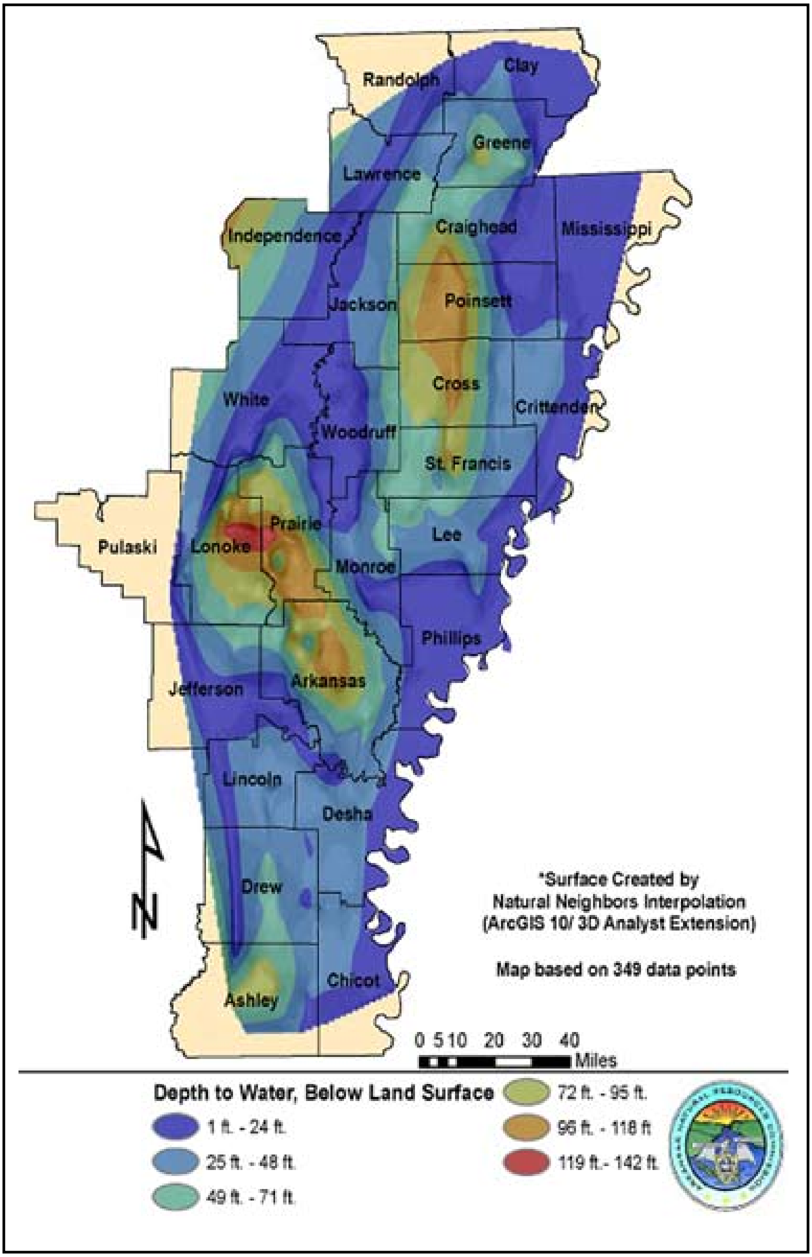



Figure 3. Alluvial Aquifer depth to water, 2010.

Because of these issues, The ANRC recently designated two additional areas of the Alluvial Aquifer as critical groundwater areas (Figure 4) (Figure 3 of the ANRC Report). This designation recognizes the existence of the water-quantity problem and encourages interested local entities to develop plans of action to address the problems. Part of the designation is to encourage federal agencies to focus financial resources in the designated areas to help conserve groundwater.

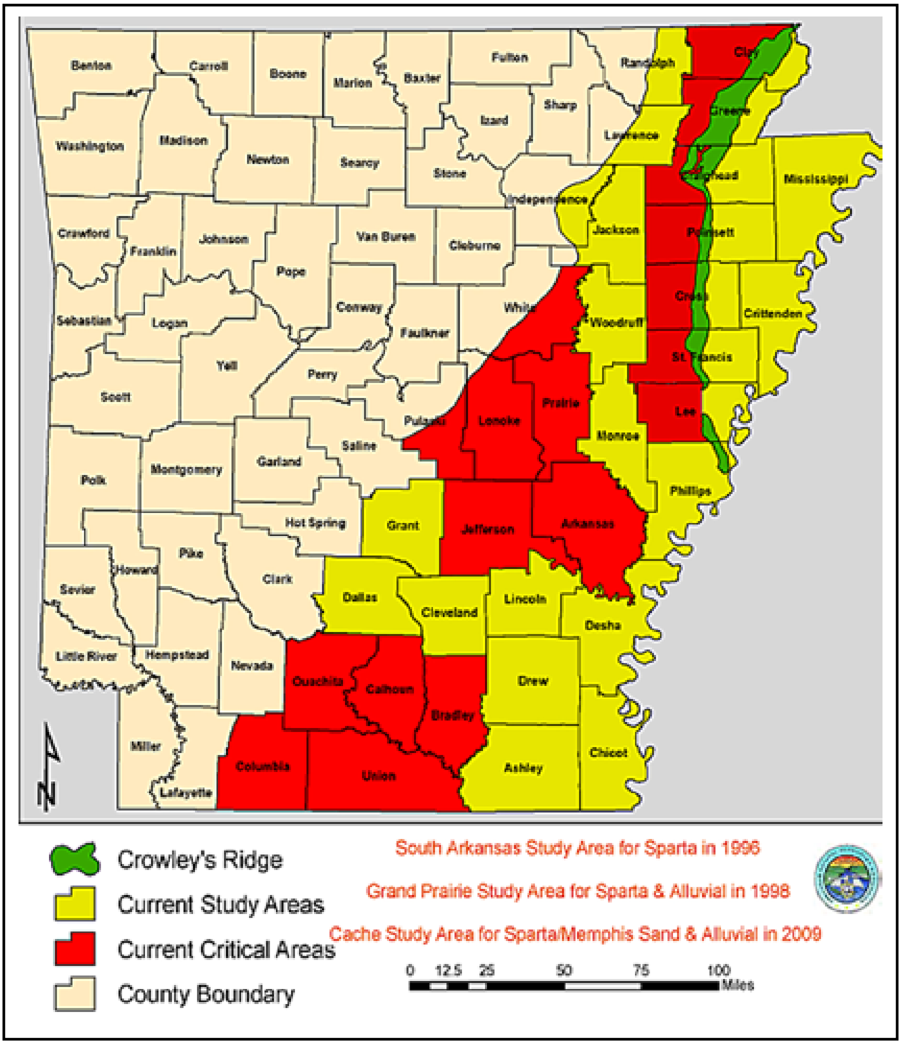



Figure 4. Critical groundwater designations.

## NRCS Approach to Conserve Water

The State Water Management Plan and NRCS planning encourage the use of surface water. Preventing further declines will require converting groundwater systems to excess surface-water systems for 50% of their water sources. Pieces of conservation may target a small aspect of the issues, but complete systems work toward solving the issue instead of band-aiding the problem. Irrigation water conservation practices are a major component in the process of reducing groundwater use when applied as a complete system.

Figure 5 illustrates a systems approach to irrigation-water management, showing where water is being used and where improvements can be made. A complete inventory, evaluation, and scheduling of water delivery allows producers to make the best use of their water resources and minimize inefficient use of ground or surface water. Typically, NRCS plans to have 50% of the water needs stored in large reservoirs, 25% of the crop needs supplied through surface runoff during the growing season, and a supplementary 25% of the water supplied through wells.

The solid line in Figure 5 separates irrigation water supply and irrigation water recovery. A complete system always includes practices on both sides of the line. Starting anywhere on the wheel eventually returns you to where you start. The goal of sustainable irrigation water use is to reuse every drop of water multiple times.

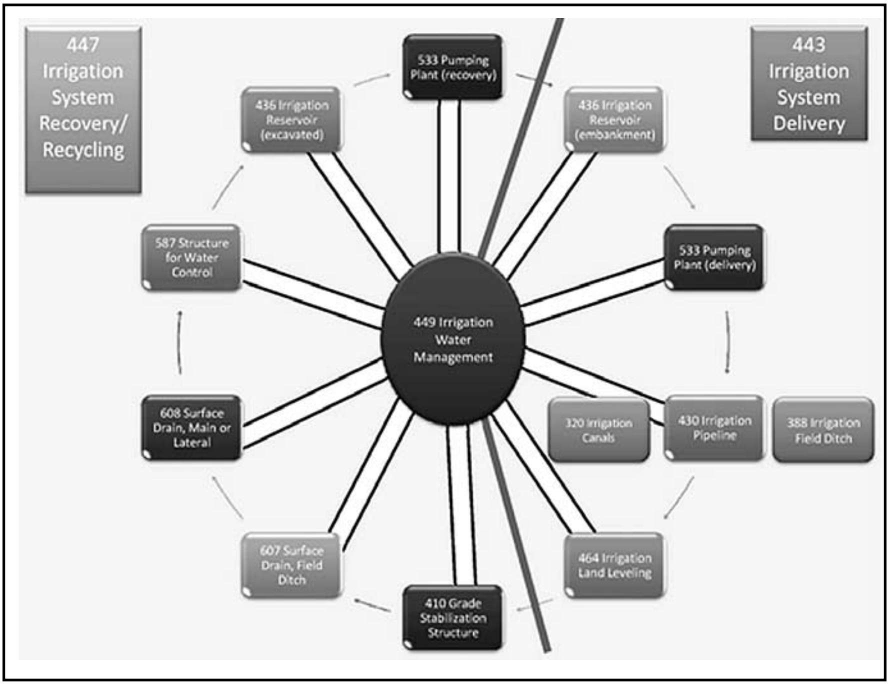



Figure 5. Irrigation water management.

The first practice and the lynchpin of the system is the irrigation reservoir, the purpose of which is to store large quantities of water (Figure 6). Ideally the reservoir is full during the non-growing season and replenished during the growing season from runoff from inefficient upstream systems and rainwater runoff.

Pumping plants pull water from reservoirs and send it to desired locations (Figure 7). They are used on both the supply and recovery sides of the solid line in Figure 5. Irrigation pipelines supply the water to fields (Figure 8).

Figure 6. Irrigation storage reservoir.

Figure 7. Electric pumping plant.

Figure 8. Robin Frazier (NRCS) checks out a pipeline.

Land leveling improves the flow of irrigation water by grading to either a very gentle slope or no slope at all. The goal is to minimize runoff and provide uniform distribution of water across the field. Leveling plays a major role in improving water-use efficiency and reducing soil erosion. At the end of the field, any extra water crosses the solid line (Figure 5) from irrigation water supply to irrigation tailwater recovery. A grade-stabilization structure at the end of the field drops water from the field to the tailwater-recovery system. This controls the water flow from the field and avoids erosion (Figure 9).

The water-control structure directs flow into or out of the excavated irrigation reservoir. The excavated irrigation reservoir is a basin to regulate water supply to the pump before sending it to a larger storage reservoir or to the field. These basins are usually pre-existing ditches that have been enlarged to allow long pump periods. A second pumping plant is used to pull water from the excavated reservoir for storage in the above-ground reservoir; many times it doubles as the delivery pump and reduces the system to a single pump.

Field ditches collect excess irrigation water (Figure 10).

## Conservation Benefits

On-farm water conservation practices have saved roughly 200,000 acre feet of water over the past 5 years in the critical groundwater area of Arkansas. On-farm conservation systems in Arkansas typically replace 25% to 50% of valuable groundwater with excess surface water. In one local project, 243 conservation systems are saving 36,600 acre-feet of ground water on 89,600 irrigated acres of farmland yearly. An aerial photo from this project illustrates how they fit on the landscape (Figure 11, Charolette Bowie, NRCS Arkansas data, personal communication).

Figure 9. Grade-stabilization structure, water-control structure, and excavated storage reservoir.

Figure 10. A surface drain.


Figure 11. Aerial photograph of an irrigation system.

This system approach fosters sustainable use of Arkansas' surface water and groundwater. Groundwater usage becomes more sustainable. Every gallon of what is recovered is a gallon that does not have to be pumped from the declining groundwater.

## Secondary Benefit: Improved Water Quality

The system approach not only sustains the groundwater, but it also provides water-quality and energy benefits.

Runoff water moves sediment and adsorbed phosphorus as well as dissolved nitrogen and phosphorus to the receiving waters. The irrigation-conservation practices minimize or eliminate runoff from irrigated fields. Every drop of water that does not run off to a receiving stream reduces loss of nutrients and transfer of sediment.

Tailwater recovery systems that include irrigation-storage reservoirs capture 100% of nutrient-laden water and sediment. In storage reservoirs, excess nitrogen is volatilized and adsorbed phosphorus sinks with the sediment.

Land leveling has been shown to significantly decrease erosion while grade-stabilization structures drop the water from the field into the reservoir and prevent gully erosion. Irrigation pipelines ensure efficient delivery, allowing water to reach all locations within the field at the same time, thereby reducing runoff and erosion.

In addition to water-quality benefits, conversion to surface water from groundwater reduces the use of energy. The energy needed to pump water from a 150-foot well is 6 times as much as from a 25-foot deep canal and reservoir system.

## New Technologies

NRCS encourages adoption of new technologies to improve water conservation, some of which are:

- Phaucet software, which allows irrigators to determine the hole size in polyethylene pipe translating into more even water distribution and less runoff.
- Automatic controls allow remote control and:
  - — Monitoring of water levels in reservoirs and tailwater recovery ditches
  - — Turning pumps on and off
  - — Monitoring of pumping-plant efficiencies
  - — Control by computer or smart phone.
- Pumping plant evaluations to:
  - — Determine peak efficiencies of pump and power units
  - — Reduce fuel costs.

## Programs that have Impacted Water Quantity and Water Quality

In a perfect world everyone would install these practices for the good of the country. However, we do not live in a perfect world, so many producers need a financial incentive

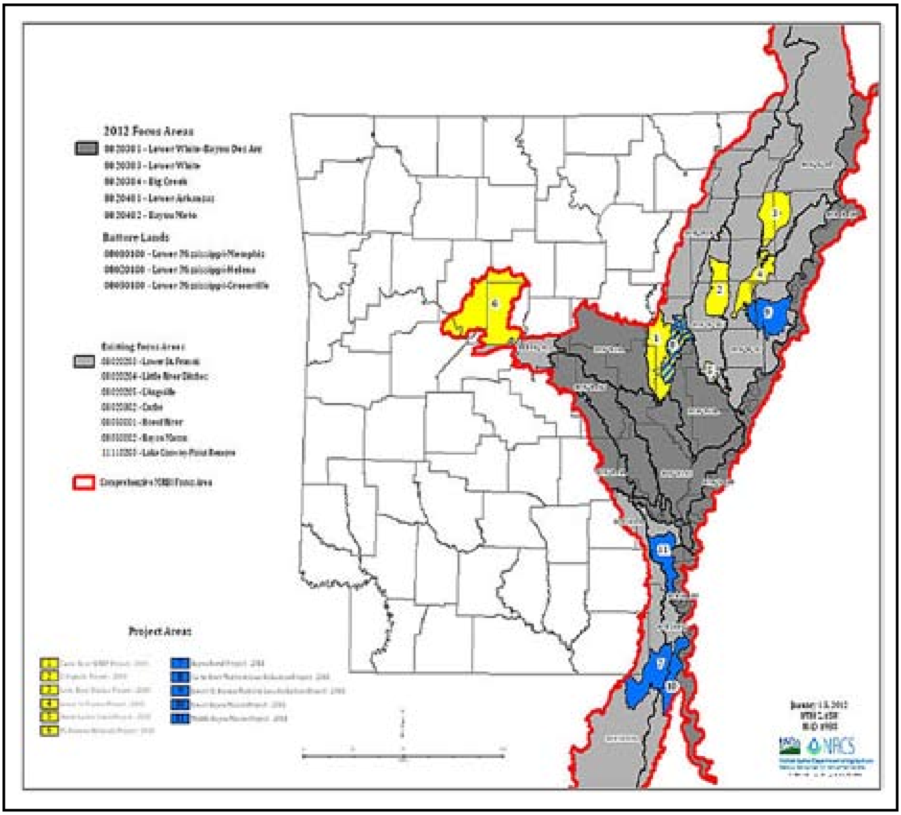



Figure 12. Mississippi River Basis Initiative, focus areas, 2012, Arkansas.

to adopt these practices. NRCS operates the Environmental Quality Incentives Program (EQIP) for a host of practices promoting environmental quality and enhancing agricultural production for local producers.

In 2011, NRCS provided $26.7 million for these practices, scattered across the state. We have recognized that targeting money to a specific watershed is much more effective than "random acts of conservation." One of the ways we have done this is through special initiatives within EQIP. The Mississippi River Basin Initiative targets specific watersheds for specific water-quality practices (Figure 12, Figure 13).

## Conclusion

NRCS's focus is to help individual landowners implement conservation practices across the landscape and in targeted locations. By providing technical and financial assistance, NRCS in Arkansas is helping people help the land and move toward water sustainability in agriculture.

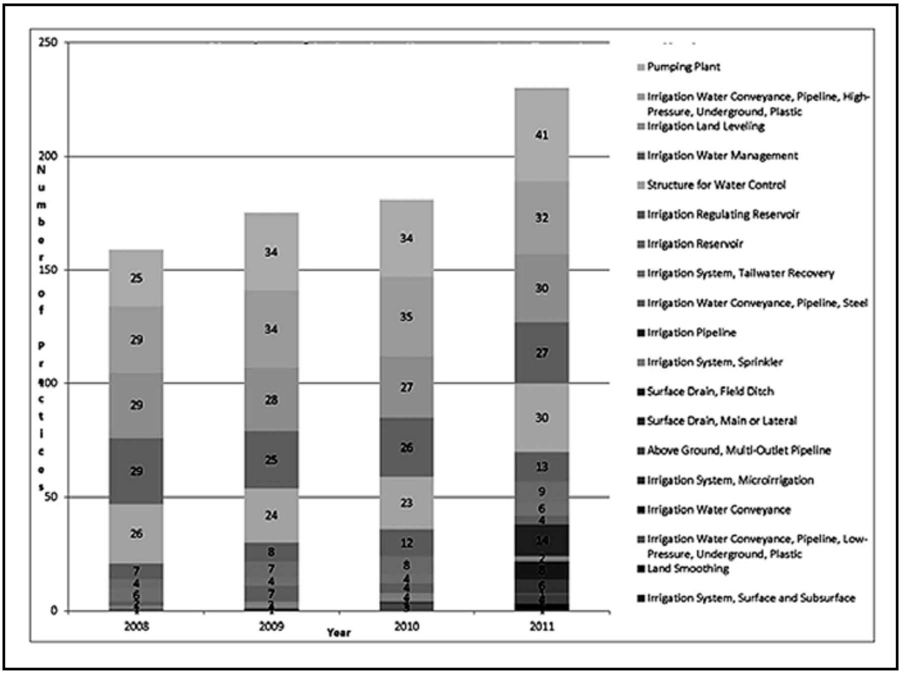



Figure 13. Number of irrigation conservation practices installed.

## References


Arkansas Ground-Water Protection and Management Report for 2010; Arkansas Natural Resources Commission 9–27, 77–78, 90–92.

Steduto P *et al.* (2012) Crop Yield Response to Water. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/nr/water/docs/IrrigationDrainage66.pdf.

US Department of Agriculture, Natural Resources Conservation Service; 2007 National Resources Inventor. http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri.

United States Geologic Survey (undated) Irrigation Water Use. http://ga.water.usgs.gov/edu/wuir.html.

MICHAEL SULLIVAN began his career with the Natural Resources Conservation Service (NRCS) as a student trainee in Lincoln, Nebraska, and then served in Arkansas, Mississippi and Arizona. As state conservationist, he leads NRCS activities throughout Arkansas. From 2004 to 2009, he served as leader of the Mississippi River Basin Healthy Watersheds Initiative, an $80 million per year effort to improve water quality, enhance wildlife habitat, and maintain agricultural productivity. He provided national leadership for partnering with the US Army Corps of Engineers and served as lead staff support to the USDA Deputy Undersecretary providing input for the Mississippi River/Gulf Hypoxia Task Force. Sullivan spent two years (2002–2004) as the NRCS National Science and Technology Coordinator. Prior to that, he worked in Little Rock, establishing and leading the NRCS National Water Management Center. He has a Bachelor's degree in civil engineering from the University of Arkansas and a Master's in business administration from Arizona State University.

# *Tyson Foods, Inc., Sustainable Water-Use Assessment: A Study Conducted by the Center for Agriculture and Rural Sustainability at the University of Arkansas*

Jamie Burr
*Tyson Foods, Inc.*
*Springdale, Arkansas*

jamie.burr@tyson.com

*People*, *Planet*, *Profit*, and *Products* are the four "pillars" of sustainability at Tyson Foods, Inc. (Tyson). Sustainability touches every aspect of Tyson's operations. Accordingly, the company defines sustainability in a way that brings responsibility and accountability into every business activity and process. Tyson's core values and their focus on sustainability guide their actions on important issues such as hunger relief, food safety, environmental protection and resource conservation, animal well-being, ethical business practices, the health and safety of our team members and returning a profit to our shareholders.

Conservation, pollution prevention, and stewardship are some of the terms Tyson uses to describe the responsibility for, and commitment to, protecting and respecting the environment. As part of the company's environmental commitment, Tyson partnered with the Center for Agriculture and Rural Sustainability at the University of Arkansas to conduct a two-stage sustainable water-use assessment. Stage I involved 100 production locations, at each of which a geo-spatial analysis utilizing seven water-scarcity indices was conducted to determine the risk of water scarcity. Stage II evaluated a cross-section of eight of the 100 locations utilizing four location-specific criteria. The criteria used in stage II comprised:

- Status of available local freshwater resources;
- Annual freshwater consumption;
- Quality of wastewater effluent; and
- Industrial-sector impact.

The purpose of this assessment was to evaluate a tool that could be used as a sustainability-performance indicator. To date, a tool of this nature is not available. A measure of water usage alone is not an indicator of sustainability, conservation, or corporate responsibility. A tool that can evaluate water use, effluent treatment, implementation of best management practices, status of local freshwater resources, and sector impact could be valuable in identifying areas of opportunity in the sustainable use of water.

## Stage I

### *Background*

Stage I utilized a suite of seven indices to evaluate whether each location was located in an area considered to be at risk for human water scarcity. Based upon agreement of the indices, the collective results provide a risk-management tool identifying future challenges to water supply of a given location. Below is a list of the indices, used as well as brief explanations.

- **Environmental Water Scarcity Index (EWSI)** is a calculation of the ratio of human water withdrawals to the total water available minus environmental water requirements. EWSI was developed by the International Water Management Institute (Alcamo *et al.*, 2000; Oki *et al.*, 2001; Smakhtim *et al.*, 2005).
- **Mean Annual Relative Water Stress Index (MARWSI)** indicates how much water is used for domestic, industrial and agricultural purposes, compared to the total runoff in the region. This is a spatial model, not a direct measurement of use (World Business Council for Sustainable Development and CH2M HILL, 2009).
- **Water Scarcity Index (WSI)** is a ratio of human water use from all sectors to the total amount of available water in the basin. An account is made for basins with strongly related flows (Phister *et al.*, 2009).
- **Annual Renewable Water Supply Per Person (ARWSP)** is the annual amount of water available in a region per person (Falkenmark, 1990).
- **Human Water Security Threat (HWST)** indicates areas that contain catchment challenges such as pollution, high dam density, high consumptive-water loss, human water stress, and biotic factors. Each challenge has a weighting factor that drives the score (Vörsömarty *et al.*, 2010).
- **Water Supply Stress Index (WaSSI)** evaluates the water demand and availability for 2100 different 8-digit hydrologic unit code (HUC) basins in the continental United States (Sun *et al.*, 2008).
- **Threatened and Endangered Species Richness (TESR)**, developed by the US Army Corps of Engineers (2005), evaluates the number of threatened or endangered species in a given 8-digit HUC basin.

### *Results*

One hundred Tyson locations in 22 states throughout the United States were analyzed against the suite of indices. In order to evaluate agreements between indices and assess vulnerability, if three or more of the indices indicated "extreme scarcity," "scarcity," or "stressed," the particular location was considered to be highly vulnerable to water scarcity. If two or fewer indices indicated agreement, the location was considered to have low vulnerability. It is important to note that this subjective arrangement has no correlation with the actual condition of the watershed. Distinguishing between high and low vulnerability only represents the general agreement between the indices.

Of the locations analyzed, 13 were considered to be vulnerable to scarcity by four or more of the indices. There were 21 locations in watersheds in which three of the seven indicated vulnerability to scarcity, for a total of 34 locations considered to be highly vulnerable. The remaining 66 locations were considered to have a low vulnerability to water scarcity by having 0, 1, or 2 indices indicating vulnerability.

### *Discussion*

Due to the large land mass associated with an 8-digit HUC basin, the status of local water resources is not accurately portrayed by each index. Each of the indices is an indication of water use, not water consumption. For instance, most food plants use "x" gallons per day, but the vast majority of that water is treated either on-site or by a publicly owned treatment works and returned to the water cycle. The indices are a great tool to point out where opportunities may exist, thereby focusing attention on locations that may be at risk through developing water-conservation plans or other best management practices.

## Stage II

### *Background*

The assessment conducted as part of Stage II offered a site-specific review of sustainable water use, which is calculated by assigning a weighting for each of four factors:

- **Local Water Scarcity.** This factor comprises 51% of the total score. It is calculated by taking the average score of five of the eight indices in stage I and the blue water[1] scarcity index (BWSI) (World Resources Institute, 1998). Each of the stage-I indices and BWSI values provide a score between 0 and 1. The average of the six indices is subtracted from 1 and then multiplied by the weighting factor of 51 to obtain the Sustainable Local Resources Score.
- **Local Industrial Sector Impact.** Industrial water-use impact considers the amount of water used by the specific industrial sector and expresses it as a fraction of the total water usage. Water use is reported by the USGS at the county level for all of the US. Total industrial-sector water use is determined by reported values from industrial self-served supplies and public water use. Of the total public supply, 58% is used by domestic users, with the balance being used by agriculture and industry. It is assumed that 60% of the balance (USGS, 2005) is used for agriculture, leaving 17% for industry use. This amount of water along with total industrial self-served water use represents industry water use by county. The industrial sector impact represents 5% of the score.

[1]Blue water is fresh surface and groundwater, *i.e.* in lakes, rivers and aquifers.

- **Sustainable Water Use.** This factor takes into the account the location's blue-water footprint[2], or the actual amount of water consumption (also called water footprint). Consumption includes water incorporated in products, evaporation, or transferred to a different watershed. Consumption is expressed as a percent by dividing the blue-water footprint by total withdrawal (% Consumption = Blue-Water Footprint / Total Water Withdrawal). The sustainable water-use score is then calculated by subtracting % consumed from 1 and then multiplying by 26 (weighting factor for sustainable water use).
- **Facility Water Use.** An international guideline for effluent discharge of pH, BOD[3], TN, TP, oil and grease, and TSS was established by the International Finance Corporation World Bank Group in 2007 (see Table 1). Each location receives 3 percentage points for each water-quality parameter met as "required" by the effluent guidelines in Table 1. Locations with the "excellent" criterion in Table 1 receive an additional 2 percentage bonus points for each parameter. If a location discharges to a public or municipal wastewater-treatment system, the location receives full credit for all parameters; however, it is not eligible for bonus points. The total percentage points are then added with the other factors.

*Table 1. Effluent guidelines for facility wastewater discharge (International Finance Corporation World Bank Group, 2007).*

| Pollutant | SI unit | Guideline Values | | |
|---|---|---|---|---|
| | | Excellent | Required | Poor |
| pH | | | 6–9 | <6 or >9 |
| BOD | mg/L | <15 | 30 | >30 |
| Total N | mg/L | <5 | 10 | >10 |
| Total P | mg/L | <1 | 2 | >2 |
| Total suspended solids | mg/L | <20 | 50 | >50 |
| Oil and grease | mg/L | <5 | 10 | >10 |

## *Results*

Tyson selected eight sites representing a business unit and geographic cross-section, comprising three poultry-slaughter, one beef-slaughter, one pork-slaughter, one rendering, and two further-process locations. Each of the individual factor scores and the total scores for each location are illustrated in Table 2.

As mentioned above, the pure use of water is not a standalone metric for sustainability. In addition to other factors, one must also consider the actual consumption of water as a measure of sustainability. As depicted in Figure 1, the amount of water consumed at each of the subject locations is a low percentage of total withdrawal.

[2]Blue-water footprint is the volume of surface and groundwater consumed as a result of the production of a good or service.

[3]Biochemical oxygen demand, total nitrogen, total phosphorus, total suspended solids.

| State | Local water-scarcity score (51) | Water-use score (26) | Wastewater-quality score Score | Bonus | Total | Industrial-impact score | Total score (5) |
|---|---|---|---|---|---|---|---|
| GA | 41.59 | 25.99 | 15 | 8 | 23 | 4.47 | 95 |
| SC | 41.36 | 19.5 | 18 | 0 | 18 | 4.54 | 80 |
| NM | 39.28 | 19.7 | 18 | 0 | 18 | 4.93 | 50.3 |
| NE | 38.45 | 22.19 | 12 | 4 | 16 | 4.57 | 78.9 |
| VA | 37.47 | 22.38 | 9 | 4 | 13 | 3.46 | 80.2 |
| MO | 36.13 | 24.87 | 9 | 4 | 13 | 3.64 | 80 |
| NC | 34.13 | 22.62 | 9 | 4 | 13 | 4.50 | 74.2 |
| IA | 7.66 | 22.62 | 9 | 4 | 13 | 4.51 | 79.4 |

*Table 2. Score of each location, broken down by factor.*

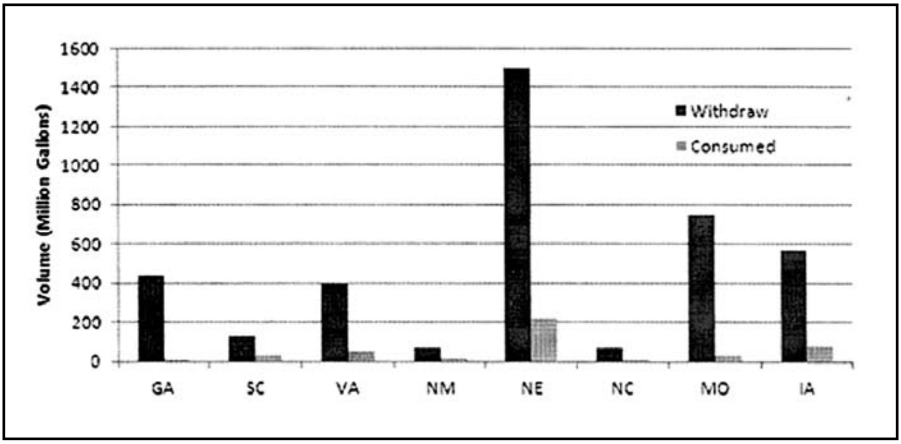



Figure 1. Water withdrawn and consumed by location.

## *Discussion*

The scoring system in stage II does not give a grade, nor is it indicative of poor water management or non-sustainable water-management practices. The score provides a comparison between locations and provides a baseline to identify opportunities to improve.

An area of opportunity in improving each location's score would be ensuring all wastewater-quality data are submitted. In the cases of the locations in Georgia, Virginia, Nebraska, North Carolina, Missouri, and Iowa, the scores could be improved by three to nine points if all of the wastewater-treatment data had been submitted. A comparison of the possible scores assuming full credit for all wastewater parameters, plus bonus points, is illustrated in Table 3.

*Table 3. Current and potential scores.*

| State | Current sustainability score | Potential sustainability score |
|---|---|---|
| GA | 95 | 100 |
| SC | 80 | 80 |
| NM | 50.3 | 50.3 |
| NE | 78.9 | 90.9 |
| VA | 80.2 | 95.2 |
| MO | 80 | 95 |
| NC | 74.2 | 89.2 |
| IA | 79.4 | 94.4 |

Another opportunity for an increase in each location's score would be in the implementation of best management practices such as water reuse. However, one must note that the United States Department of Agriculture closely regulates water use in processing plants.

The lowest scoring location is the New Mexico site. The location lost most points due to being located in an extremely water-scarce area. The opportunity for bonus points is lost at this location due to discharging to a publicly owned treatment works. The South Carolina location is also ineligible for bonus credit due to discharging to a publicly owned treatment works; hence the reason Table 3 does not indicate an increase in potential sustainability score.

## Summary

The stage-I assessment provided information for 100 Tyson locations in 22 states. Utilizing the seven indices, the assessment indicated that 34 of the locations may be at risk of water scarcity. The assessment provides a tool that can be used as risk analysis; however, these indices account for withdrawal only and not for consumption of water. Due to the large area that an 8-digit HUC may cover, it is important to evaluate the local water availability to get a more accurate picture of water scarcity at the location level.

The assessment contained in stage II brings sector impact, wastewater quality, and water consumption into the equation. This allows a more detailed analysis of water sustainability. Due to the amount of data required within stage II, only eight of the 100 locations were evaluated. These eight represent a cross-section both of geographical and of business units. Results from the stage-II evaluation indicated scores between 74.2 and 95 for seven of the eight locations, and a low score of 50.3 for the eighth location due to extreme water scarcity in New Mexico. Some of the scores could have been improved if all wastewater-treatment data had been supplied.

## Acknowledgments

Tyson commends Dr. Marty Matlock, Ms. Amber Brown and Mr. James McCarty (all of University of Arkansas) for their work on this project.

## References


Alcamo *et al.* (2000) World Water in 2025: Global Modeling and Scenario Analysis for the World Commission on Water for the 21st Century. Kassel World Water Series Report No. 2, pp. 21–49. Kassel: University of Kassel Center for Environmental Systems Research.

Brown AR *et al.* (2011). Tyson's Sustainable Water Use Assessment—Stage I Geographic Watershed Analysis. Springdale: Tyson Foods, Inc.

Brown AR Matlock MD (2012) Tysons Sustainable Water Use Assessment—Stage II Assessment. Springdale: Tyson Foods, Inc.

Falkenmark M (1990) Rapid population growth and water scarcity: The predicament of tomorrow's Africa. Population and Development Review (Population Council) 16 81–94.

International Finance Corporation World Bank Group (2007) General EHS Guidelines: Environmental Wastewater and Ambient Water Quality. Environmental, Health, and Safety (EHS) Guidelines. Washington, DC: World Bank Group.

Oki *et al.* (2001) Global assessment of current water resources using total runoff integrating pathways. Hydrological Sciences Journal 46 983–995.

Pfister *et al.* (2009) Assessing the environmental impacts of freshwater consumption in LCA. Environmental Science and Technology 43 4098–4104.

Smakhtin V *et al.* (2005) Taking into Account Environmental Water Requirements in Global-scale Water Resources Assessments. IWMI The Global Podium. http://podium.iwmi.org/podium/Doc_Summary.asp.

Sun GE *et al.*, (2008) Impacts of climate change, population growth, land use change, and groundwater availability on water supply and demand across the conterminous U.S. Watershed Update 6(2) 1–30.

US Army Corps of Engineers (2009) Army Installations Water Sustainability Assessment: An Evaluation of Vulnerability to Water Supply. Champaign, IL: CERL.

USGS (2005) Public-Supply Water Use. http://www.ga.water.usgs.gov/edu/wups/html.

Vörösmarty C *et al.* (2010) Global threats to human water security and river biodiversity. Nature 467 555–561

WBCSD & CH2M HILL (2009) The Global Water Tool. Geneva: World Business Council for Sustainable Development. www.wbcsd.org.

World Resources Institute (1998) Water Resources and Freshwater Ecosystems. Earthtrends.wri.org.

JAMIE BURR earned BS and MS degrees in agronomy from Missouri State University and has worked for Tyson Foods since 1999. His responsibilities include environmental and safety aspects of live production, including sustainability, compliance, governmental relations, and impending regulatory changes. Mr. Burr sits on several committees and work groups throughout the United States as a representative of the poultry and swine industries in an effort to provide input on policy, regulations, sustainability, and research.

# *Changing Role of Agriculture in Environmental and Consumer Issues*

Q&A[1]

Moderator: Marty Matlock
*University of Arkansas*
*Fayetteville, Arkansas*

Steve Pueppke (Michigan State University, East Lansing): For Jamie Burr—I'm wondering what messages you are getting from your customers about sustainability and water use. And are you seeing trends that they are making decisions about whom they purchase from based on their scores on things such as what you are talking about?

Jamie Burr: Absolutely. Customers are developing an index to score each of their suppliers in all areas of sustainability. One of our representatives is in Chicago because McDonald's is working on their score card right now. And let's take an animal-welfare issue—gestation crates for sows. Many restaurants have said that by a certain date they are not going to source pork from facilities that have gestation crates.

Anna McClung (USDA-ARS, Stuttgart): Having so many plants across the country, do differences in state water policies affect what you look at as your long-range plans in terms of ownership and stewardship of water?

Burr: Yes. Every day, additional restrictions are placed on discharge quality of water, which impinges on the sustainability of the location in question. If it will cost too much money to upgrade a wastewater-treatment plant, then the facility will be on a short list, so to speak.

[1]Some of the audiorecording, from which this written record was prepared, was of poor quality, rendering it impossible to accurately represent dialogue. Every effort has been made to provide a faithful transcription.

Hongshun Yang (University of Minnesota, St. Paul): Mr. Burr, you mentioned checking pH and BOD[2]. We know that beef and pork have *E. coli* O57 for example. When you discharge water, do you need to inactivate food-borne pathogens?

Burr: There are standards for discharging *E. coli*, but I don't know what they are. I'm sorry, but that's not my area of expertise.

Marty Matlock: I can throw you a lifeline on that one. We don't have an international set of water-quality standards, but, in the United States, all discharges have bacterial limits. These metrics are based on UN water-quality standards—UNESCO-type standards that are not just an arbitrary definition of a good BOD. It's a very good point and, to progress to a global standard, we would have to define those bacterial limits.

Bill McCutchen (Texas A&M University, College Station): Another question for Jamie Burr on sustainability. What is Tyson's intention for moving outside the United States? With all the added regulations and the expenses, are you going to quote-unquote outsource?

Burr: It's going to be more market-driven more than regulation-driven. China is a big area for us to expand into because of increasing *per-capita* consumption.

Richard Moore (Ohio State University, Wooster): If you expand into the China market, will you engage some aspect of sustainability with their water resources?

Burr: Other countries have different views on compliance and ethics, whereas, as a US company, we have a very strong ethics program.

Anna McClung (USDA-ARS, Stuttgart). Mr. Sullivan, with the different sorts of water-conservation practices that are being implemented on the farm, two questions. One, to what extent are the costs of those changes being incurred by the landowner versus other resources helping to bear those changes? And then the other question: speaking to critical groundwater-use areas, have some been overused to such an extent that not just conservation will be needed but transition to different agricultural systems?

Michael Sullivan: In terms of the cost for the projects that we enter in on, we offer cost share at a rate of 60% to 70%. But some of the practices have caps on them and most of the time the producer ends up paying a higher percentage of that cost. We receive requests for our assistance that far exceed our ability to provide the cost share, so, in some cases, the producers are bearing the entire cost of these projects themselves. Your second question was how bad has the problem gotten? There's recognition that, certainly, we can't continue using groundwater at current rates. We're not making decisions for landowners

[2]Biochemical oxygen demand.

on what crops they grow. If they are going to continue to grow rice and soybeans, they are recognizing that they are going to have to find additional sources of water, and I think the answer is with surface water. So, there is a sustainable solution, but it will be very different from what we've done in the past.

Ray Vester (E&M Farms, Stuttgart): Michael, I have tail-water recovery systems—how much of a benefit are they to nutrient capture, as far as stopping nutrient run-off, keeping it on the farm, returning it and circulating it?

Sullivan: Very efficient. If you have a tail-water system, you are basically capturing 100% of the nutrients and the sediment. It depends on what you are comparing it to. If you don't have the tail-water system, how efficient are you managing your system and how much run-off water do you have, and how much sediment and nutrients are running off with that? It's the one practice that can ensure us we are going to achieve water-quality benefits.

McCutchen: Are there feasibility studies on facilitating recharge of aquifers here in Arkansas? Is it technically feasible? Would it ever be economically feasible?

Sullivan: I'm aware of some studies. I'm not aware of any that show it to be economically feasible. Recharge occurs naturally, but withdrawals far exceed the rates of recharge.

McCutchen: Are there any "Manhattan projects?" Water is the natural resource for all of us, so economics may not be the problem 20 years down the road. It may be a necessity to recharge. Are any of those types of studies going on?

Sullivan: We do have excess surface water available, which has been recognized by the state. Several projects in the state are at various levels of implementation, in terms of importing surface waters from rivers to get them to crop lands. That's probably the most economical means of transporting water from one location to another.

McCutchen: I have read articles about pipelines from Canada to United States, not carrying petroleum but water. Any validity to that?

Sullivan: Most of what I've heard was more in terms of states like Texas taking water from Arkansas. That's been part of the impetus for Arkansas's water-planning efforts.

Matlock: Jamie represented the processors' perspective and he mentioned the issue of consumption. Mike, can you address the hydrologic process of using water—the difference between putting water on the field and consumption? What is it we consume in agriculture when we use water?

Sullivan: When we think of consumptive use, that's just what it is. It's the amount of water that is actually used. Other water may be lost in the system and not actually used that could be recaptured. And so, from an agricultural standpoint—I don't know what the exact numbers are, but if you look at where we show that we can improve our efficiencies from 55% to 75%, in a lot of cases historically those may be where we had a lot of tail water running down the ditches, and not efficiently utilized, which either could be captured and reused or more efficiently used to begin with. Here in Arkansas, especially compared to some of the states in the west, we have a long way to go in terms of improving our efficiencies by reducing losses of nonconsumptive portions.

Ken Korth (University of Arkansas, Fayetteville): Sarah, you mentioned Walmart's surveys of their suppliers. Are they using them to make decisions about whom to buy from? Must suppliers have a minimum score?

Sarah Lewis: Probably they will, but they have not said that they will choose one supplier over another based on sustainability. Price and quality and all the regular things that always have been in play—consumer demand is a huge component of this—and sustainability will be part of the conversation. It's about how to make improvements in the life cycle around these key issues. And that is across the board, not just Walmart. It's Marks and Spencer, Tesco and others; that's the message that we are hearing.

Hank Venema (International Institute for Sustainable Development, Winnipeg): What's the strategy to elicit consumer awareness? Are you going to have a logo? Can you elaborate on the strategy for rolling out to consumers?

Lewis: The mission of the Sustainability Consortium is not linked directly with consumers. Companies in the electronics sector—Dell, HP, Best Buy and some others—have collectively said that they will display a label. Companies in the Food, Beverage and Agriculture sector are not interested in a label, which would be inappropriate for such a complex value chain. We are providing information, and, in this life cycle, water is an issue.

Venema: An editorial comment—a consumer logo for your sector will come, but it is probably 10 years away.

Lewis: Well, some companies tried that, Tesco for example, but couldn't find a method applicable across the board. They couldn't communicate consistently and so they saw the value of TSC in harmonizing content, facilitating the education of their consumers using their own strategies outside of TSC.

Matlock: A question for the panel as a whole. From your perspective on the water-supply chain, if you can measure only two metrics, two bits of data, what would they be and why?

Sullivan: One would be related to water quantity and the other would be associated with water quality. We have not done a good job in monitoring our effectiveness in conservation practices that have been applied, and so, on the water-quantity side, we need good data on actual water use and water savings. On the water-quality side, the same thing—one example would be the Discovery Farms approach here in Arkansas looking at edge-of-field monitoring data on what's happening with sediment and nutrients. So, my two metrics would be good water-quantity and water-quality monitored data showing the effects of conservation practices.

Burr: The first one would be the cost of wastewater treatment to go from, for instance, a 3 milligram per liter phosphorus discharge to a 1 and then to an 0.1 and then the second one—which we already do—is gallons of water per pound of product.

Lewis: I'll be a little bit broader. Big initiatives already are taking place in water and energy, so I would say what benchmarking tool are you using and what multi-stakeholder process are you involved in that's facilitating progress towards addressing these issues? We are all looking at doing these important things already, so getting together on these issues is what I would be looking for.

McLung: Following up on that, what would be some scientific knowledge gaps that you feel would help the community to address sustainability in the future?

Lewis: One example is the work I mentioned with GIS. There's a need to link key issues and strategies to geographic region. Are we talking about a watershed at the eight digit hydrologic unit code? Are we talking about the country level? Region? Ecoregion? Global ecoregion? What are the issues at the regional or watershed level and how can they be communicated to stakeholders?

Burr: I'm going to stick with the cost side again and say the cost-benefit of either a water-quality standard TMDL[3] or a more stringent permit limit.

Sullivan: There is still a lot that we don't know about the effects of conservation practices beyond the edge of field. We are getting to the point we have some good information on what is happening at the edge of field, but less so when there is interest in what is happening downstream at the bottom of a small watershed or down into a river basin or river scale with long-time delays and responses. A lot could be gained with additional information there.

Lewis: There's a very strong need for improved traceability for the supply chain and water. Someone mentioned it—water is a necessary, across-the-board, resource. Everyone needs it. And if there is anything that could help us have improved traceability across the supply

[3]Total maximum daily load.

chain, it's water. From the time the seed goes into the ground to when the package arrives at the recycling center, what's the water-use efficiency? We don't have that information.

Tom Riley (University of Arkansas, Little Rock): Sarah, I want to put you on the spot a little bit. I want you to put on your other hat, your community participant hat. What's the role that community has in this issue as it relates to both industry and the other perspectives that are represented here?

Lewis: I encourage everyone to get involved with their local watershed partners and communicate with their locally elected officials about ways to provide incentives that then can be communicated up through the life cycle.

Venema: I agree with you on water foot-printing in products. Carbon foot-printing on products is done in Europe. Phosphorus is a conservative substance that can be tracked in principle through the value chain as well, and it's non substitutable. It's actually really crucial to world food security. Any thoughts about the logic of a phosphorus trace in value chains?

Burr: I'm not real sure how to address that. Dr. Sharpley talked about the broken chain, so to speak, of taking the phosphorus out of Florida and taking it to the Midwest and then taking it to the livestock-growing regions. How do we complete that loop and take that phosphorus back out of the regions that have livestock and put it back up in the grain-growing belt?

Lewis: That is an important question and, right now, what we have captured is energy use at fertilizer production. I would say that is an information gap in the research. We have looked at fertilizer production and fertilizer application, which are key life-cycle issues, but we have few references to the nonrenewable aspects of phosphorus. That's a good point and I'm going to take it back to the researchers.

Venema: I noticed that you are collaborating with the Arizona State University who, in addition to their sustainability initiative, have a sustainable phosphorus initiative. You might want to talk to colleagues at Arizona State.

Lewis: We will get those folks connected.

Vester: What do I tell the farmers who ask me what will it cost me and what will I gain from it?

Lewis: I'll start. Economics is an important part of sustainability. The Sustainability Consortium communicates environmental and social impacts for a life cycle. Our members then take that information and decide what improvement opportunities are feasible, which may provide economic returns.

Burr: Sustainability is more than just water, like I mentioned earlier. I had a graph that showed feed efficiency over time with broilers. One of the biggest things with sustainability is increasing production, doing more with less. That's one of the things that the farmer should realize. If we can do more with less fuel or whatever, that is where we need to go.

Sullivan: At the NRCS, if you ask "What will it cost me?" we would ask you some questions back. We have a conservation planning process where we work with you one-on-one. You will tell us your objectives which will begin to tie into natural resource concerns, sustainability issues. We will help you inventory your resources, look at alternatives, put a plan together that will include cost and options, then you will make decisions on how you want to invest your resources.

Vester: But the next question they will then ask is, "What benefit do I get?"

Sullivan: From our standpoint, if we have done a good job of conservation planning, that will be included in there. It will have benefit to you from a production standpoint. It will also show environmental benefits. It will then show opportunity for additional federal assistance for implementing those practices that you would like to put into operation and avenues then for applying for cost-share assistance to help you install the practices.

Vester: For the person who raises rice and sells it, what will be their benefit? They will have a cost and will it increase their return?

Sullivan: That's part of the equation, looking at your returns and everything else.

Vester: I agree, and that's what frightens them. They know it will cost and they are at the bottom of the chain. That's the fear of the farmer: "Yes, we know we have to do this. We know it is good for the environment. We know we will spend more." But, typically in an agricultural situation, you spend more and the only thing that happens is the margin shrinks a little more. We farmers are price takers, not price setters.

Matlock: Jamie could you respond to that? I know you feel the same pinch.

Burr: Without profit you are not sustainable, and that's all there is to it. One of the four pillars of Tyson's sustainability program is profit. I'm sorry to answer a question with another question, but a greater concern for me is, "When it comes to third-party verification, who is going to pay for that?" Going back to your question—if it doesn't make a profit I don't know how it can be done. Again, sustainability is more with less.

Lewis: One thing I am hearing from our members is the need for sustainable supply. Maybe the major reason they care about sustainability is sustaining the supply chain. If we are growing things in areas where there is a groundwater-scarcity risk, then that is a supply issue. How do we sustain the supply? That's an economic issue.

Korth: Earlier someone talked about growers who are near the White River and have plenty of water, with the Alluvial Aquifer being replenished. I'm guessing it's hard to convince them to go the extra mile to make the capital expense to do these things that you are suggesting. Is that what you see? How do you convince that person that it is worthwhile and, likewise, the person further away for whom the cost is more again: how do you convince her/him that it is worth the significant investment?

Sullivan: That's a tremendous challenge for us because, primarily, the way we work is landowner by landowner, and there is a lot of variation. If you are in the area of the most significant cone of depression, producers are looking to conserve water any way they can. If you have producers who have easy access to either groundwater or surface water, they are not going to be nearly as interested. I'm not sure what the answer is other than offering opportunities to adopt conservation plans to address their resource concerns and needs to help them ensure they are sustainable from an environmental standpoint as well as financially. That may be as good as we can hope for.

Ernest Girouard (Louisiana State University, Rayne). The topic here is water and 70% of the water is used to produce food. We all eat, so sustainability of water is everyone's problem. We've finally gotten around to saying that sustainability without profitability at the producer level will not work. We are going to have to involve more technology, more interest, more participation at the farm level, to solve the problem. Producers can't solve the problem on their own and federal money keeps going down. How are we going to raise additional money? One of the most important issues is to overcome the bad taste at the producer level, when sustainability, in recent history, did not have a profitability component to it. NRCS has been very successful with obtaining additional industry support by partnerships. I was a recipient of one of those partnerships in my program. How do we raise additional money with additional partnerships? Sustainability is really important at the producer level. But it is even more important to the companies that buy the products. And it's even more important to the consumer.

Sullivan: I will add that Dr. Girouard in Louisiana has been very effective working with conservation districts and working with groups of producers in small watersheds to address problems. Something I failed to mention—we have the opportunity to focus on small or micro watersheds where we can make a great difference. In Arkansas we recognize that we need more partners. Our funding opportunities from the federal side are certainly dwindling, however we have seen more interest from NGOs in working with us, even beyond some of our traditional groups like the Nature Conservancy and Ducks Unlimited. Recently, here in Arkansas, we embarked on a project with Heifer International looking at sustainable food systems in East Arkansas, in economically depressed areas of the delta, and how we can help producers be viable in producing crops in a sustainable manner and also providing locally available food, vegetables and those kinds of things. We are seeing some interest from other organizations. Certainly we have a long way to go though.

Burr: I'm going to take a different approach and say that our producer groups need to do a better job of telling the story of agriculture. There is a bumper sticker, I see it all over, *Farmers Were the Original Conservationist*. And that is very true. Our commodity groups, especially those that get paid check-off dollars, need to be doing a better job of telling the story. The Pork Board has been doing probably one of the better jobs; a carbon footprint is out and they are working with Dr. Matlock and his team on a water footprint. Next will be land and then air. The other commodity groups need to do the same thing.

Lewis: That's what I observe too. It's about getting together with your stakeholders and communicating your stories in a harmonized way so you are focused on the key issues. A lot of progress can be made on water with across-the-board impacts if that communication can increase. Right now there are silos and people aren't communicating across them. If you do nothing else, try to improve communication across the supply chains.

Matlock: We are the 24th meeting of the National Agricultural Biotechnology Council. Starting with Mike, then Jamie and then Sarah, give me your best optimistic view of the role of biotechnology and your worst fear about the role of biotechnology in addressing the challenge of sustainable water and agriculture.

Sullivan: I'm an optimist by nature and, in my presentation, I said that we can be sustainable from a water-use perspective. We use a lot of water here in Arkansas. We get a lot of publicity because of that. But I am optimistic. We can be sustainable in our agricultural water use with the crops that are being grown currently. My concern or fear is that we may not be moving as far or as fast as we need in the proper direction. We are directionally correct and we are moving toward the correct solutions. Looking at some of the problems that have developed, we need to accelerate the pace at which we are moving forward.

Burr: I'll start with my concern and my concern is how we feed 9 billion people in the next 40 years with the same amount of land and the same amount of water.

Matlock: What about biotechnology Jamie? The first transgenic meat animal was approved by FDA this year. How does that affect your industry?

Burr: Good thing you come up with easy questions, Marty. I'm not sure how to answer it.

Matlock: Do you see a role for biotechnology in water efficiency in the animal?

Burr: Oh absolutely, especially in terms of water use in the processing side, because there is a cost to buy that water and there is a cost to treat that water.

Lewis: As a multi-stakeholder organization, we present key issues and biotechnology is one of a variety of ways to address them. If you want water-use efficiency, if you want to fertilizer-use efficiency, biotechnology is a way to get there. But there are also other ways. We say: work on addressing these issues and if biotechnology makes a difference in water-quality issues, efficiency and yield, then it is an important tool.

Venema: It strikes me that the biotechnology discourse is around crop agriculture primarily. I haven't seen much discussion around biotechnology for bioremediation. That would be a practical way to deal with some of the externalities from agriculture. I proposed a biomass-based approach to deal with our bioremediation issues. We are using a volunteer invasive, but all kinds of work could be done around optimizing species for bioremediation.

Moore: Back to the talk on Lake Erie and the timing of 1994, when we saw a reactive soluble phosphorus increase, which corresponded with the adoption of Roundup Ready soybean in that area. The connection with glyphosate in the water is another issue. We don't know much about it yet, but that's an issue that connects with biotech.

Lewis: Biotechnology and GMOs are being used to address multiple hotspots, as we call them, across life cycles, including water. Are you asking about transporting those across different regions?

Moore: No, in the case Roundup Ready soybeans, the herbicide is being transported in the water.

Lewis: That's the tradeoff, and it's something that has to be communicated. If you're not using GMOs and you are spraying herbicides heavily then there are water-quality implications: eutrofication, acidification and so on. So what is important is how you are addressing the impacts of the practices you are using.

Kristen Gibson (University of Arkansas, Fayetteville): Those who grow fresh-produce crops that are minimally processed and ready to eat, are getting mixed messages about conservation efforts. Buffer zones can become breeding grounds for food-borne pathogens coming from the wildlife. Now they are actually ripping out buffer zones because of the food-safety issue. How do you manage the risk of implementing conservation efforts—for water sustainability—where food safety is a concern?

Matlock: Are you referring to the baby leaf spinach *E. coli* contamination from feral pigs?

Gibson: That's one of them. Recently with the new Farm Bill, the discussion has come up in the leafy green produce marketing agreement in California—the Center for Produce Safety. These are questions that stakeholders have. We are asked to adopt conservation measures but, on the other hand, we are trying to protect our crops and allay food-safety concerns.

Matlock: The story goes that *E. coli* contamination in leafy green baby spinach came from feral pigs that were getting access to the field through the conservation reserve riparian zone that was put in. And so they they had to destroy the riparian zone area. That's the conflict on landscape, and a good question for Mike.

Sullivan: In Arkansas I'm not aware where that has become a significant issue, probably because we don't grow many vegetable crops. However, I'm aware that it has been an issue in other states and could be an issue here. I would hope that, as we work with producers, those would be the types of things we would consider when putting conservation plans together and, where needed, we would have opportunities to address concerns. Feral pigs have become a big issue here. Currently, we don't have a national policy for how we can provide support and assistance for those types of invasives. I know APHIS and others are working on that and have worked on some pilot projects in the southeast part of the state. One of the things that we will be looking at in the coming months—in fact we have a team assembled—is what are the natural resource problems associated with such an invasive species and what we can do from a conservation perspective to help deal with them. Should we be providing financial assistance to help producers trap such invasives?

Matlock: Clearly that illustrates the interconnected nature of the complex system we call agricultural production. Decisions aren't easy and that has been a common theme through all of the presentations.

Burr: We deal with a similar issue, not in your particular produce example but in poultry as it relates to ABD influenza and using surface water as the drinking water source for poultry. You have to eliminate whatever is causing it or you have to eliminate the habitat. Or you have to treat the water. You have to take a multidisciplinary approach to solving that issue.

Ralph Hardy (National Agricultural Biotechnology Council, Ithaca): Let's take another crack at the biotech area and impacts. Bovine growth hormone: my understanding is that it increases the amount of productivity per unit input. Presumably you are reducing the amount of water input, for example, into an animal. You may be reducing the amount of phosphate going through and the phosphate in the manure. There was a porcine growth hormone in the pork industry that was supposed to provide leaner pork. Now that got somehow rejected along the way. You know, there are other things like that in biotech that we should be looking at that would be beneficial to the broad area we are talking about.

Matlock: Sarah, do you want to tell the story of the Dairy Innovation Center meeting during the week that Walmart pulled rBST milk off the shelf?

Lewis: I'm sorry I'm not familiar with the details of that particular story. I'm going to focus on tradeoffs. One thing that is important to recognize is that sometimes we don't have all the information. If you are using growth hormone you may be saving water. You may be reducing the amount of phosphorus reaching surface waters, and so on, because the yield is increased per unit of input. But the trade-off that we are hearing from our stakeholders is that there may be health issues and animal-welfare issues. Sometimes it's a value judgment on what is more important. And science has a hard time addressing that. As scientists, we can provide all this information, but, in the end, at some point there is a value judgment: "What is more important to me? What do I care more about?" Maybe someday science will tackle that, but right now I don't know that we want to.

Matlock: I see rBST as an example of where we, as scientists, weren't measuring things that would have informed public opinion and retail policy in a way that would have been valuable for the industry and for our producers. We hadn't measured the fact that it reduces greenhouse gas by 13% per gallon of milk and the other metrics of sustainability that would have improved by the use of that particular product for liquid milk. Since those measurements hadn't been collated in a way that was scientifically vetted and reported, there was no counter argument to the fear. In a cost-benefit analysis, you have to have the benefits and the costs, and all the consumers saw were costs. They didn't see benefits. And that is an area of sustainability science where we can do a better job of making sure we understand objectively where the benefits are and where the risks are and then, as Sarah said, people can make their decisions.

McCutchen: Jamie, we are going to keep shooting at you on the biotech issue. Hopefully, this is an easier question. Maybe you don't want to speak about genetically modified animals and Tyson's stance, but what about the reality of marker-assisted selection or breeding, especially with poultry. A number of land-grant universities are using marker-assisted breeding in crops—in addition to transgenic traits—for increased productivity. Land-grant universities are using those for let's call them specialty crops or orphan crops. I could see marker-assisted breeding, understanding the traits—you talked about feed efficiency—in cattle for example. Is Tyson investing in that type of research?

Burr: Yes, Tyson owns Cobb-Vantress, a poultry-genetics, chicken-only, company. That research is done in-house. Cobb is based out of Siloam Springs. Their geneticists select for qualities just like what you are talking about. Over the past 20 years through genetic selection, about a point of feed conversion improvement per year has been their target.

McCutchen: Would you have any interest in working with land-grant universities to develop these types of approaches?

Burr: Cobb collaborates with the Center of Poultry Excellence at the University of Arkansas.

# PREPARING FOR FUTURE CHALLENGES OF WATER ISSUES

# *The Economics of Pest-Controlling Biotechnology*

David Zilberman
*University of California*
*Berkeley, California*

zilber11@berkeley.edu

No manuscript[1].

[*Editors' note*—The topics discussed by Dr. Zilberman included:

- GM seeds reduce crop damage
- Impacts of GM on yield
- Other effects of GM
- Estimated yield effects of GM seed vary by trait and region
- Impacts of GM in adopting countries
- Implications for land use
- Implications for food security
- Herbicide tolerance and double cropping
- Impact in cotton
- Bans and excessive regulations prevent GM from reaching its potential

The presentation was based on
Sexton S Zilberman D (2011) Land for food and fuel production: The role of agricultural biotechnology. In: Agricultural Economics (Zivin J Perloff J, Eds.). Chicago: The University of Chicago Press.]

[1]Inferior quality of the audiorecording precluded transcription of Dr. Zilberman's verbal presentation.

**DAVID ZILBERMAN'S** areas of expertise include agricultural and environmental policy, marketing, risk management, the economics of innovation, natural resources, water, biotechnology, and biofuels. He is a fellow of the Agricultural & Applied Economics Association (AAEA) and of the Association of Environmental and Resource Economists. He is the recipient of the AAEA Outstanding Journal Article Award (2011), the AAEA Publication of Enduring Quality Award (2005, 2010), and the UNESCO International Cannes Prize for Water and the Economy (2000). Dr. Zilmberman has published 250 refereed articles in *Science*, the *American Economic Review*, *Econometrica*, the *American Journal of Agricultural Economics*, the *Journal of Environmental Economics and Management*, among others, and has edited 13 books. He has served as a consultant to the United States Environmental Protection Agency, the United States Department of Agriculture, the World Bank, the Food and Agriculture Organization of the United Nations, and the Organization for Economic Co-operation and Development. He received his BA in economics and statistics from Tel Aviv University, and his PhD from the University of California at Berkeley.

# *Optimizing Agricultural Water for Food, the Environment and Urban Use*

Reagan M. Waskom
*Colorado State University*
*Fort Collins, Colorado*

reagan.waskom@colostate.edu

Irrigated agriculture remains the primary consumptive use of water in the United States; however, population growth, environmental needs and changing societal values are driving a reallocation of water away from agriculture. It is projected that, by 2030, 33 million additional people will be living in the western United States, requiring approximately 30 billion more gallons of water for consumption per year (Western Governors' Association, 2006). In much of the semi-arid areas of the world, new water resources will be in limited supply, particularly if remaining watersheds, aquifers and streams are protected from additional withdrawals for crop or livestock production. Water continues to move from farms to cities, and the social, economic and environmental results of these water transfers are important and sometimes are not anticipated or well understood. As a consequence, growth and subsequent water conflicts are occurring in agricultural areas in the West and across the nation, where key water resources are often fragile and scarce, as pointed out in the Bureau of Reclamation's Water 2025 Report (Figure 1). As this trend advances, there is legitimate concern about our ability to meet projected food demands under reduced irrigation water supplies.

From a global perspective, modern agriculture has its roots in the so-called "green revolution" that began with introduction of high-yielding rice and wheat cultivars in the 1960s. It is less well recognized that the "blue revolution" in irrigation expansion took place alongside the development of shorter-statured high-yielding cultivars (Figure 2). Global expansion of irrigated lands appears to have leveled off and major irrigated regions in the western United States are under considerable stress to reduce water consumption to meet environmental, energy and municipal water demands. The promise of "more crop per drop" makes for a catchy slogan, but we need to carefully examine the implications of reduced irrigation water on food supplies and producer risk exposure as we plan adaptation strategies.

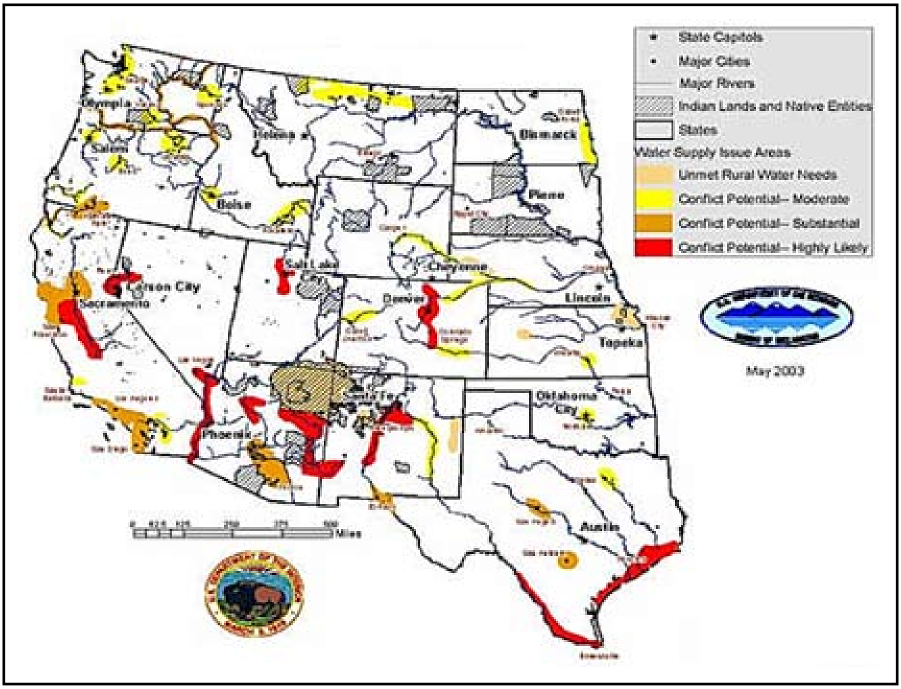



Figure 1. Potential water-supply crises by 2025 in the western United States (DOI, 2005).
(Areas where existing supplies are not adequate to meet water demands for people, for farms, and for the environment.)

Freshwater ecosystems, already impaired in many basins, will be further threatened under projected climate forecasts, requiring more water for environmental flows, not less. Endangered-species concerns, such as those over longfin smelt in the San Francisco Bay and Delta[1], will potentially disrupt agricultural diversions at critical times during the cropping season, when producers are most at risk. Agriculture currently consumes over 70% of total freshwater used by humanity, competing with the energy sector, which comes in a distant second. Even so, energy and other users can easily out-spend agriculture for water. It is important to recognize that while only 15% of total US crop acres are irrigated, approximately 40% of total crop value comes from these acres, including many of the economically important grain, vegetable and fruit crops.

In simple terms, optimizing agricultural water use involves growing more food while reducing agriculture's environmental footprint. Agricultural water managers must address competing demands of urban development, energy and ecosystems. Perhaps what is needed is a new approach that couples agriculture and the environment as an integrated

[1]http://www.fws.gov/cno/press/release.cfm?rid=375.

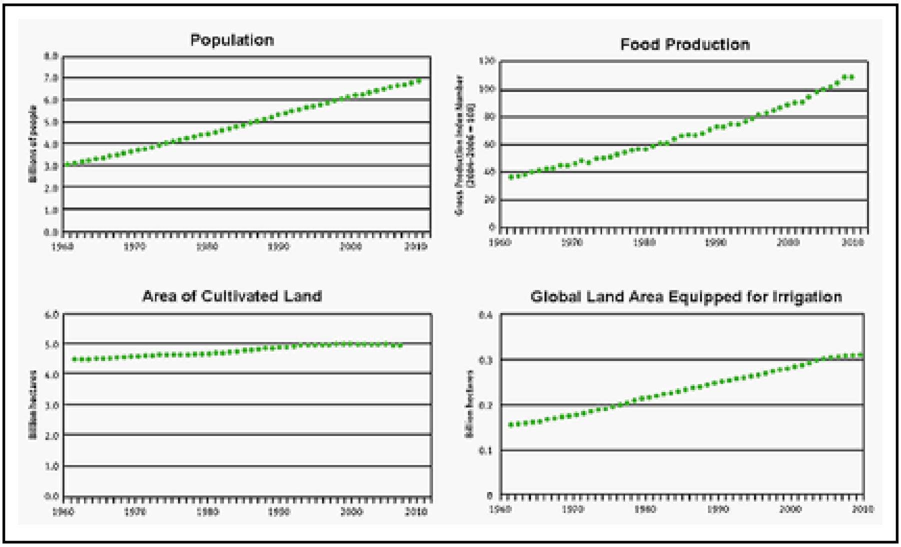



Figure 2. Trends in global food systems (from Beddington *et al.*, 2011)

system, rather than separating these sectors as distinct problems or sectors. In this article I will use case studies as examples that touch my home state of Colorado to examine these points and prospects for new approaches—the Ogallala Aquifer and the Colorado River Basin. I'll argue that both the problem and solutions to global water problems lie within agriculture.

## Case Example 1: Ogallala Aquifer

Groundwater and surface water have historically been thought of as distinct sources in terms of public perception and legal framework. Unlike surface-water supplies where flooding, depletion, and contamination problems are readily apparent, groundwater problems may take years or decades to manifest themselves into recognizable concerns. This has historically led to a lax attitude regarding groundwater, even though systematic depletion of aquifers such as the Ogallala has long been documented. However, through national and regional assessments like the USGS NAWQA programs, there is a growing recognition of problems associated with falling groundwater tables, increased drinking water contamination, and a better understanding of the linkage between ground- and surface-water resources that has resource managers struggling to develop cost-effective solutions (USGS, 2004).

The High Plains Aquifer underlies a 111-million acre area (174,000 sq mi) of the eight Great Plains states of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming. It is one of largest freshwater aquifer systems in the world and is the most intensively used aquifer in the United States, providing 30% of the total withdrawals from all aquifers for irrigation (*Maupin and Barber*, 2005). The High Plains agricultural economy runs on water from the Ogallala. The crop-, livestock- and meat-processing sectors are the backbone of the regional economy and provide many jobs. Irrigated crops provide feed for livestock, which are part of a large meat-packing industry in the region. An estimated 15 million cattle and 4.25 million hogs are raised annually over the aquifer (Waskom *et al.*, 2006). Approximately 23% of the cropland overlying the Ogallala is irrigated, accounting for 94% of the total groundwater use on the High Plains (Sophocleous, 2010). Irrigated acreage on the High Plains Aquifer increased rapidly from 1940 to 1980, but did not change greatly from 1980 to 2002, stabilizing at approximately 14 million acres.

The Ogallala formation underlies 80% of the High Plains and is the principle geologic unit of the High Plains Aquifer. An estimated 165,000 wells currently pump from the aquifer (Waskom *et al.*, 2006). The aquifer is recharged very slowly in the semi-arid environment of the Great Plains, creating essentially a nonrenewable resource in many areas. Recharge rates vary from 0.024 inches per year in Texas upwards to 6 inches per year in parts of Kansas and Nebraska. Substantial pumping over the past 40 years has led to water-level declines of up to 150 feet and 50% of the saturated thickness in localized areas of the aquifer (Table 1). Although the rate of decline has slowed in recent years, the downward trend continues in many areas, threatening the long-term viability of an irrigation-based economy.

*Table 1. Water level changes in the High Plains Aquifer, predevelopment to 2009 (adapted from McGuire, 2011).*

| State | Area-weighted average water-level change (feet) | Change in water in storage (million acre-feet) |
|---|---|---|
| Colorado | –13.2 | –19.4 |
| Kansas | –22.8 | –64.7 |
| Nebraska | –0.9 | –16.6 |
| New Mexico | –15.1 | –11.4 |
| Oklahoma | –12.3 | –13.0 |
| S. Dakota | 0 | –0.5 |
| Texas | –36.7 | –145 |
| Wyoming | –0.4 | –2.6 |
| Total | –14.0 | –273 |

Falke *et al.* (2011) investigated linkages between groundwater pumping from the High Plains Aquifer and stream fish habitat loss, and found most refuge pool habitats dried completely or lost more than half their volume, disconnecting from other pools by late summer. Under conservative modeling scenarios, they predicted that maintaining current water-table levels and refuge pools for fishes would require a 75% reduction in groundwater pumping, which is not economically or politically feasible. Given widespread streamflow declines, ecological futures are bleak for stream fishes in the western Great Plains under current groundwater-pumping regimes.

Because water-level declines in the High Plains Aquifer have been large, they have substantially decreased the saturated thickness of the aquifer in some areas. Reduced well capacity in most areas means lost crop production, as both irrigated acres and crop yields decline. A reduced well yield means that irrigation is less effective at meeting crop evapotranspiration (ET) during peak crop-water-use time periods. Not only do yields decline with aquifer depletions, but yields also become more variable. The lost income and increased variability in income threatens the local economy and the future viability of the agricultural operations depending upon products grown on Ogallala water.

Currently, both Colorado and Nebraska are looking for ways to reduce pumping and to decommission wells to meet the compact compliance terms of the lawsuit on the Republican River. Given current commodity prices, producers are highly interested in new hybrids and varieties that might have greater yield potential or stability under reduced irrigation allocations. Producer response to reduced water availability on the High Plains includes:

- Rotational and split cropping with dryland crops or fallowed land
- Limited, deficit and partial season irrigation
- Shift to sunflowers, sorghum, wheat, forage crops
- Higher level of irrigation scheduling and water management
- Reduced tillage to maintain surface residue, decrease evaporation and increase precipitation capture
- Re-nozzle sprinklers and remove pivot end guns
- Use of EQIP, CREP and other farm programs to retire lands and reduce pumping

## Case Example 2: Colorado River Basin

The Colorado River Basin is one of the most critical sources of water in the Southwest, spanning seven US states and Mexico. This river's remarkable reach includes providing water to more than 30 million people, irrigating nearly four million acres of agricultural land, and serving as the limiting resource for at least 15 Native American tribes, seven National Wildlife Refuges, four National Recreation Areas, five National Parks in the United States and a Biosphere Reserve in Mexico. The river's energy powers more than 4,200 MW of electrical capacity to households and industry. However, the river and its ecosystems are at risk as increasing water demands and climate change are poised to collide with a fully appropriated basin.

Agriculture in the Colorado River Basin is driven by irrigation, with about 4 million acres of land receiving irrigation from the river system, representing about 15% of all crop receipts and 13% of all livestock in the United States. The vulnerabilities that climate change portends for the basin are serious, but we should probably recognize that severe weather, population growth and the attendant municipal, energy, industry and recreational water needs already stress irrigated agriculture in this Basin. The agricultural industry in the Basin as a whole is heavily dominated by livestock production and attendant feed and forage needs. Subsequently, the irrigated crops grown are dominated by grass hay, alfalfa, and feed grains in the Upper Basin, whereas the value of vegetable and fruit crops becomes increasingly significant as you move downstream towards Arizona and California.

Historically, the Colorado River drainage had 42 native fish species, including 30 endemic species found in no other river system. Of these endemic species, 4 are extinct, 12 are listed as endangered, and 4 are threatened. Approximately 60% of the fish species found in the basin are found only in the Colorado River Basin. Flow needs to sustain native fishes have not been fully quantified, but are very valuable from economic and ecological standpoints. For the Native Americans who live in the Basin, most of their water rights are senior to the more traditional rights held by agriculture and the cities. Some of the tribal reserved water rights remain to be quantified; creating uncertainty about how much of the river will be allocated to the tribes. Mexico also has a thriving agriculture that depends on this river. In addition, the Basin supports a vibrant recreational economy in the southwest United States, with the Grand Canyon at its heart.

Particular areas in the Colorado River Basin (most notably lower central Arizona) have already seen significant reductions in irrigated agriculture as land near growing urban areas is converted to housing or dried up for urban water. The distribution of farms is trending toward many small, irrigated holdings that produce smaller shares of household income, and fewer large farms that support the majority of irrigated cropping. It is unclear how this might influence future conservation and water-management practices or how it might influence future water transactions. This basin has been slower to adopt sprinkler and drip-irrigation techniques because of the particular needs and economics of the dominant production systems. Adaptation to societal pressure for more water for recreation, environment and municipal use has largely been through market transactions that dry up agriculture, either temporarily or permanently.

## Understanding Crop-Water Needs and Opportunities to Optimize

While the public widely perceives that agriculture can easily be managed to conserve water, crop growth and yield are tightly coupled to ET. In general, 70% to 80% of the total crop consumptive water use is via transpiration from the plant canopy. There is a direct relationship between the amount of ET and crop biomass because plant stomata must be open for a plant to assimilate carbon. When plant stomata are open, water vapor is lost to the atmosphere. In this way, 99% of the water that is taken up by the plant is returned to the atmosphere in the form of water vapor.

The amount of ET and the relative percent of consumptive use evaporation vs. transpiration are dependent upon the following factors:

- Crop type (cool v. warm season and maturity length)
- Percent of canopy cover (stage of development and plant population)
- Irrigation system and frequency of application
- Residue cover (*e.g.*, mulch/tillage system)
- Soil moisture status

When evaluating agricultural water-conservation improvements, it is important to distinguish between practices that lead to improved irrigation application efficiency and those that lead to reduced consumptive use. Irrigation-water-use efficiency is defined as the ratio of water applied compared to water consumed by a crop (*i.e.*, ET). Increasing irrigation efficiency is likely to reduce losses from deep percolation and runoff (thereby altering historical return flow patterns), but it may or may not materially affect the amount of water consumed by the plant. Much of the water lost to these inefficiencies will return to the river or groundwater system for use by downstream diverters.

In most cases, upgrading irrigation systems increases water-use efficiency, but does not necessarily reduce consumptive use. Reducing consumptively used water can result when one or more of the following occurs:

- Irrigated acres are decreased
- Crop selection is changed from a summer crop to a cool-season crop
- Crop selection is changed to one with a shorter growing season
- Deficit irrigation is practiced, applying some amount less than full ET over the growing season
- Evaporative losses from the field surface are reduced as a result of conservation tillage, mulching, and or drip irrigation

Most of the difference in consumptive use between crops can be explained by canopy cover, season of active growth and length of growing season. Crops grown during the cool season, such as winter wheat, are subject to lower atmospheric demand and, thus, lower ET rates. Reducing the length of crop-growing days also can reduce irrigation demands. These differences in season-long consumptive use as a result of growing day length or growing period are illustrated in the ET data for one location in Table 2.

*Table 2. Growing season and cumulative ET for various crops at Holyoke, Colorado (adapted from USDA-NRCS Colorado Irrigation Guide; accessed online May 2012).*

| Crop | Growing season (Average dates) | Growing season (Days) | Seasonal ET (inches/season) |
|---|---|---|---|
| Alfalfa | 3/20–10/10 | 204 | 35.2 |
| Sugarbeet | 4/25–10/10 | 168 | 29.9 |
| Corn/grain | 5/5–10/5 | 153 | 25.4 |
| Soybean | 5/25–10/5 | 133 | 16.4 |
| Spring grains | 4/1–7/25 | 115 | 15.2 |
| Dry bean | 6/1–9/5 | 96 | 18.7 |

## Agricultural Water Conservation Techniques that Reduce Crop Consumptive Use and Nonproductive Consumptive Losses

Current state water laws generally allow irrigators flexibility in crop types, irrigation timing, methods, and application rates. If properly managed, crop consumptive use or nonproductive consumptive losses may be reduced by the following practices:

- Lower water-use cropping systems
- Acreage fallowing
- Shorter-season/cool-season crops
- Limited/deficit irrigation
- Removal of pivot end guns and reduce acres
- Ditch piping and lining (reducing evaporation, ET, and seepage)
- Crop-residue management and mulching
- Phreatophyte[2] control

We currently have many technologies for increasing the effective use of water, but we will need new mechanisms and greater incentives for optimizing agricultural water use. Promising approaches include:

- Developing new crop varieties and cropping systems
- Sharing water between agriculture, cities, and the environment
- Streamlining water markets
- Transitioning to rainfed and limited irrigation strategies
- Modernizing water-distribution networks
- Developing economic tools to help producers determine highest economic use of their available water
- Linking life-cycle of energy and water inputs to production systems
- Developing agricultural systems that are resilient to uncertain water supplies and drought; and
- Improving agricultural water-management institutions, policies and organizations.

Additionally, our catchments—particularly forest and rangeland—must be actively managed to sustain necessary water resources and preserve functioning ecosystems and watersheds.

Blum (2009) argues that crop breeding for water-limiting conditions leads to reduced yield and reduced drought resistance as we are fundamentally limited by the biochemistry of photosynthesis. The notion of more crop per drop sounds good, but it may be misleading. Water-use efficiency (WUE) is an old irrigation concept that has moved into

---

[2]A deeply rooted plant that obtains a significant portion of its water from the saturated phreatic zone or the capillary fringe above the phreatic zone.

the crop-improvement vocabulary. Transpiration efficiency is what breeders should be most concerned about: the amount of water transpired per unit of $CO_2$ fixed. The goal should be to maximize the $CO_2$ fixed per unit area under drought or water-limited or full-irrigation conditions. Effective use of water (EUW) implies maximum soil-moisture capture and uptake for transpiration—a more important target for yield improvement in water-limited environments. It is well known that moisture stress at reproductive stages is most yield limiting. Given that limited- or deficit-irrigation scenarios are a likely future in many basins, one significant problem is supplying water at later critical growth stages. Deficient irrigation portends higher levels of producer management and higher levels of risk.

The full promise of biotechnology for significantly greater crop-water productivity appears to lie somewhere in the future and may depend upon some fundamental restructuring of plant physiology and morphology. Significant genomic innovation for WUE has been relatively slow to develop, whereas our water problems are immediate. Our agricultural productivity depends upon creating new mechanisms for increasing food productivity using less water—we need new solutions in the next few decades to sustain our productivity. Many of the technological advances needed for water optimization in agriculture are already well in hand; for example, more-efficient irrigation systems, soil, water and evapotranspiration monitoring and information systems, water reuse, and rain-fed cropping systems have been designed to capture and optimize precipitation efficiency. It is often the institutional, economic and social barriers that constrain producer adoption and further implementation.

## References

Beddington J *et al.* (2011) Achieving Food Security in the Face of Climate Change: Final report from the Commission on Sustainable Agriculture and Climate Change. CGIAR Research Program on Climate Change, Agriculture and Food Security. http://ccafs.cgiar.org/sites/default/files/assets/docs/climate_food_commission-spm-nov2011.pdf.

Blum A (2009) Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. Field Crops Research 112:119–123.

Department of the Interior (DOI) (2005) Water 2025: Preventing Crises and Conflict in the West. http://www.doi.gov/water2025/supply.

Falke JA *et al.* (2011) The role of groundwater pumping and drought in shaping ecological futures for stream fishes in a dryland river basin of the western Great Plains, USA. Ecohydrology 4 682–697.

Maupin MA Barber NL (2005) Estimated Withdrawals from Principal Aquifers in the United States, 2000. U.S. Geological Survey Circular 1279. http://pubs.usgs.gov/circ/2005/1279/.

McGuire VL (2011) Water-level changes in the High Plains aquifer, predevelopment to 2009, 2007–08, and 2008–09, and change in water in storage, predevelopment to 2009: U.S. Geological Survey Scientific Investigations Report 2011–5089. http://pubs.usgs.gov/sir/2011/5089/.

Sophocleous M (2010) Review: groundwater management practices, challenges, and innovations in the High Plains aquifer, USA—lessons and recommended actions. Hydrogeology Journal 18 559–575.

US Geological Survey NAWQA (2004) Significant Findings Irrigated Agriculture Land-Use Study—Central High Plains. http://webserver.cr.usgs.gov/nawqa/hpgw/sigfinds/CALFINDS.html.

Waskom R *et al.* (2006) Outlook on the High Plains Aquifer. 2006 Great Plains Soil Fertility Conference Proceedings, Volume 11. pp 122–128.

Western Governors' Association. 2006. Annual Report: Building a Sustainable West. Denver, CO. http://www.westgov.org/wga/publicat/annrpt06.pdf.

**REAGAN WASKOM** serves as the director of the Colorado Water Institute and as director of the Colorado State University Water Center. He is a member of the Department of Soil & Crop Sciences faculty with a joint appointment in the Department of Civil and Environmental Engineering at CSU. In addition, Dr. Waskom serves as the regional director of the USDA-NIFA Integrated Water Program and supervises the CSU Extension Water Outreach program and personnel. His recent research and outreach projects include: Colorado River basin ag sustainability; irrigation water optimization in water-limited environments; evaluation of alternatives to ag water transfer; evaluation of Western households' perceptions and preferences for water use and acquisition; evaluation of municipal water-conservation programs; and development of best management practices for crop production. He received his BS and MS degrees from Texas A&M University and his PhD from Colorado State University in environmental soil science.

# *A Producer-Led Framework to Assess Water Sustainability in Agriculture: The NISA Example*

Jed Colquhoun
*University of Wisconsin*
*Madison, Wisconsin*

colquhoun@wisc.edu

The trajectory of human population growth is often in stark contrast with decreasing natural resources needed to support that population. The national and global needs for food, feed, fiber and energy continue to increase relative to water availability and provide a prime example of increasing demands on limited resources. Similar resource constraints have been observed in industrial sustainability, hence the commonly used saying, "measurement equals management." Unlike industrial efforts, agriculture has largely failed in "measurement" efforts, and, as such, it has proven difficult to capture and communicate changes in economic, environmental and social sustainability over time. The National Initiative for Sustainable Agriculture (NISA) provides a reasonable mechanism for agricultural producers to document advancements along the sustainability continuum and communicate improvements in resource use, such as water, throughout the supply chain.

## Challenges in Assessing Agricultural Sustainability

### *A Case Study: Wisconsin Central Sands Region Water and Agriculture*

The central sands region of Wisconsin provides a prime example of an evolving agricultural production system in public conflict over a critical input resource: water. Wisconsin ranks second among US states for processing vegetable harvested acreage and production, and third in processing vegetable production value, the majority of which is grown in the central sands region. Common processing vegetable crops in the area include potatoes, sweet corn, green beans, green peas, carrots, cucumbers and onions. Overall, specialty crop value, including process, contributes about $6.4 billion to the state's economic activity and accounts for nearly 35,000 jobs (Keene and Mitchell, 2010). About half of the processing vegetables and the vast majority of the potatoes included in calculating this value are enabled by irrigation.

The central sands region is dominated by coarse-textured soils low in organic matter and water-holding capacity. Agriculture in the region expanded greatly over the past 60 years from about 15,000 ha irrigated in the 1960s to about 74,000 ha in 2000. Groundwater serves as the irrigation source with the water table lying 3 to 20 m below the soil surface and ranging from 10- to 60-m deep. The region also contains about 80 small lakes, many wetlands, and streams of high recreational and economic value. Most surface-water bodies are supplied directly by the groundwater. Since 2000, low water levels have been observed in some streams and lakes in the region. Kraft *et al.* (2012) concluded that irrigation has decreased stream base flows and lake-water levels substantially in recent years.

Substantial historical data on depth to groundwater from monitoring wells and lake and stream levels are available for many locations across the central sands. Similar data relative to changes in agricultural production systems, water withdrawals and consumption, and cropping patterns is minimal and of questionable accuracy. For example, what is the role of diversifying crop rotations, selecting shorter-season crops and varieties, improving irrigation technology (such as low-pressure drop nozzles, nighttime irrigation scheduling, or drip) or adapting cropping systems to climate change on water use? This lack of data challenges the ability of policymakers, agricultural professionals and the public to make informed decisions on appropriate resource use and agricultural best-management practices that will protect the groundwater resource, but may be reasonably resolved by implementing a sustainability-assessment program that captures change over time.

### *Assessing Sustainability from Consumer and Producer Perspectives*

Although sustainable agriculture certainly is not a new topic, the use of "sustainability" as a marketing concept is. Despite challenging economic times, the interest in sustainability continues to grow at a rapid pace. Yet, from producers to consumers, much confusion exists about the meaning and value of such efforts.

***The vast majority of consumers are either unaware of sustainability efforts or are confused by them.*** While "green," "eco-friendly," "fair," "sustainable" and other terms are very popular within marketing groups, consumers are not necessarily engaged at a similar level. An International Food Information Council (IFIC) consumer survey indicated that 50% of consumers knew nothing at all about the concept of sustainability in food production, while 23% knew a little (IFIC, 2010). Consumers who are aware of the concept are often confused by it, to the point where the Federal Trade Commission (FTC) proposed revisions in 2010 to their *Green Guides*—a document that provides guidance on appropriate use of the aforementioned terms in product marketing—for the first time in over a decade. According to FTC chairman Jon Leibowitz (FTC, 2010):

> *In recent years, businesses have increasingly used "green" marketing to capture consumers' attention and move Americans toward a more environmentally friendly future. But what companies think green claims mean and what consumers really understand are sometimes two different things.*

***Thus far, sustainability in food production doesn't add value—it is an expectation.*** Much of the effort around sustainability in agriculture adds cost to production, such as additional labor costs that result from increased scouting to the actual process of documenting sustainability and enhancing biodiversity through non-crop habitat improvement. Unlike industrial processes, these efforts often have a poor, if any, return on investment. Consumers even expect "sustainable" products to be cheaper given that they ideally would require fewer inputs to produce. Authors of a 2009 Deloitte/Grocery Manufacturers Association (GMA) consumer survey on the subject concluded that (GMA/Deloitte, 2009):

> *...most shoppers would like green products to be price competitive. They often don't understand or buy into the rationale that a green product should be more expensive. Shoppers don't understand why a green product should cost more if it was manufactured with less packaging or it was transported less distance.*

This survey and others suggest that there is a strong difference between what consumers say they will purchase and what is actually in their grocery carts in the checkout lane. In the 2009 Deloitte/GMA survey, 95% of shoppers indicated that they would buy green, but only 22% actually did so. Furthermore, only 2% were committed to buying green.

Similar consumer responses were observed in marketing challenges with the Healthy Grown Potato Program in Wisconsin. The program is the result of a unique collaboration of organizations, including growers through the Wisconsin Potato and Vegetable Growers Association, University of Wisconsin, Michael Fields Agricultural Institute, World Wildlife Fund, International Crane Foundation, and Defenders of Wildlife, among others. Research that provided the basis for the standards began in the early 1980s. The developed standards are rigorous and involve all aspects of potato production from seed through crop harvest and storage. They restrict pesticide use, require the adoption of integrated pest management (IPM), and require ecosystem services beyond the agricultural fields that are designed to preserve biodiversity in the landscape. By 2005, IPM adoption among program participants increased 30 to 40% compared to the first certified crop in 2001 and pesticide risk was reduced 50%. In fact, the standards are so rigorous that not all fields enrolled in the Healthy Grown Potato Program pass; in 2006, only 35% of the fields enrolled passed the minimum bar for certification. The Healthy Grown certification process is conducted by a third-party organization hired by the growers. The investment in research and rigor of the standard have not gone unnoticed. In 2003, the collaborative team received the USDA Secretary Honor Award for Maintaining and Enhancing the Nation's Natural Resources, and has since been the recipient of several other accolades.

While it may "feel right" to grow potatoes this way, it certainly isn't cheap. Alternative pest management and production practices are often more expensive, the certification process requires employee time and a hired third-party organization, and growers are required to invest annually in the ecosystems services component of the standard.

An award-winning collaboration among academics, environmental advocates and growers, a rigorous science-based standard that has been documented to improve IPM adoption, reduce pesticide risk, and preserve ecosystem services—so, what's the problem? First, consumers aren't convinced about paying for environmental conservation, particularly in this troubled economy. Second, the potato growers have invested in a significant amount of market research and implementation into the project. After hearing about the Healthy Grown story, 70% of consumers indicated that they were more likely to purchase Healthy Grown potatoes. Moreover, of those who were interested in purchasing the product, 88% indicated that they would be willing to pay 25 cents more per bag. In 2004 and 2005, however, just over 1% of product sold was actually sold as Healthy Grown, and certainly not at a value-added price.

***Sustainability is measurable in industrial processes, but isn't easily quantified in agricultural production.*** Many of the inputs in industrial processes (including food processing) that pertain to sustainability, such as water, energy and fuel use, can be measured as easily as reading the utility bill. The impetus is often "measurement leads to management," and efficiencies or alternative sources are employed that have a rapid return on investment. Regardless of the input, such strategies save money. Cyber communication and monitoring technologies have made this process quite feasible and affordable. In fact, inputs are often monitored by the minute, with a red flag raised when they exceed goals. This technology also allows direct communication with, and participation by, consumers. In food processing, for example, the Kettle Brand® website (www.kettlebrand.com) includes a link to an online public monitoring system that reports electric generation from wind turbines on the roof of their Beloit potato-chip plant *by the minute*. This alternative energy generation is then equated in terms that consumers understand, such as gallons of fuel saved.

The description of these successes in industrial and food processing is not meant at all to belittle sustainability efforts, but rather to highlight them. The use of technology to improve efficiencies is good for the manufacturer, for the consumer, and for the planet. Unfortunately, such success stories are not typically reported when it comes to agricultural production. The sustainability parameters of interest, such as biodiversity, soil health and water quality, cannot be measured with a simple meter; they require expensive and cumbersome monitoring. Additionally, agricultural production systems are affected by climate, biological processes, and complex interactions across the landscape creating extreme variability by crop, production region and season. Thus, the one-size-fits-all approach commonly used in highly engineered processing and manufacturing plants is inappropriate. Agricultural sustainability efforts often focus on a practice-based approach given the challenges in measuring outcomes. In other words, while practice-based sustainability programs may not measure soil sediment in water, they instead ask producers about tillage practices. The National Organic Program is an example of such an approach.

***At some point, a buyer or consumer value system guides choices around sustainability.*** Agriculture is a complex biological system, confounded by broad seasonal variation and overlaid with management systems that vary by farm. Actions taken to improve an individual sustainability metric often affect several other parameters, and not always in a positive manner. For example, reducing herbicide use in favor of increased cultivation may reduce overall pesticide use, but may also increase risk of soil erosion.

Greenhouse-gas emissions in agriculture provide a striking example of the potential role of consumer values in sustainability metrics. Weber and Matthews (2008) compared the greenhouse-gas emissions associated with food production with those of food distribution. They reported that 83% of the household carbon footprint associated with food is in production and only 11% in what is considered "food miles." Four percent of the greenhouse-gas emissions were associated with transport from producer to retailer. Furthermore, the authors report that red-meat production is about 150% more greenhouse-gas-intensive than for chicken or fish. The authors conclude that:

> *…dietary shift can be a more effective means of lowering an average household's food-related climate footprint than "buying local." Shifting less than one day per week's worth of calories from red meat and dairy products to chicken, fish, eggs, or a vegetable-based diet achieves more GHG reduction than buying all locally sourced food.*

***Currently, there exists a wide gap between high-altitude metrics programs designed to capture change on a national scale and local, practice-based sustainability efforts.*** Several national efforts, currently underway, are developing programs that will capture broad change, such as at the watershed level, in typical sustainability parameters such as land and water use, energy and carbon footprint. These programs have made great headway in recent years and will be critical in the efforts to communicate advancements in agriculture to regulators, environmental advocates and the general consumer. They do not, however, instigate local engagement and change at the field level, as the intention has never been to advise someone on how to farm or develop "best management practices." Local change requires local grower engagement, regionally- and crop-appropriate best management practices and prioritization of efforts around values that are locally important. For example, the majority of the economic impact from potato and vegetable production in Wisconsin is enabled by irrigation, thus water is held as having high value by the agricultural community. In contrast, labor constraints are of relatively less concern given the mechanized nature of production in this area. The downside to local, practice-based sustainability programs is that the impact of such efforts is often not captured or communicated beyond agriculture. Additionally, the multitude of local sustainability efforts in various crops, by several entities (public and private) and without a consistent framework or process has led to challenges in duplicative programs and messaging (*i.e.* one production region is unintentionally put forward as "more sustainable" than other regions for the same crop, further confusing all involved).

## NISA as a Producer-Led Framework to Assess Sustainability Behind the Farm Gate

NISA is a producer-led federation that will harmonize sustainability efforts within a common framework, regardless of cropping system, region or farm scale, and address the challenges outlined above. The goal is not to judge the "sustainability" of agriculture, but to provide growers with an opportunity to account for their advancements over time and communicate them broadly. Participants are developing a roadmap of farm-management systems that will help producers to achieve verifiable sustainability outcomes, improve the environmental services and productivity of their farms, help their rural communities thrive, and satisfy sustainability expectations of the value chain.

These efforts will operate at the farm level; incorporate a framework of tools and technical information from a wide base of expertise and programs; and, with the support of regional and national experts, communicate sustainability-management systems that are valid across crops and regions.

As indicated earlier, several agricultural sustainability programs have emerged in recent years, ironically in part to reduce the likelihood that producers will have to fill out multiple assessments for a single raw agricultural product. The NISA approach is unique in several ways.

***NISA is producer-driven and adaptable to changing times.*** This bottom-up approach allows producers to be at the table in designing sustainability assessments that are regionally- and crop-appropriate, scaled to improve sustainability at the field level, founded on the best available science and balanced among the social, environmental and economic sustainability pillars. Such an approach also accounts for the diversity of agriculture, is neutral to production techniques, and won't competitively pit production regions or crops against each other. The alternative—those outside agriculture determining producers' fate—isn't appropriate or sustainable itself.

***NISA is complementary to other sustainability programs, such as Field to Market and the Stewardship Index for Specialty Crops, and not redundant or overly cumbersome.*** The assessment-based approach implemented by NISA will cover the gaps that currently exist in outcome-based programs. Several of these gaps exist because outcomes are difficult, expensive or invasive to quantify. The combination of assessment- and outcome-based data will create a holistic sustainability message. Sustainability assessments cannot be overly cumbersome, otherwise increased costs will be realized by the producer and the supply chain, thus limiting implementation.

***NISA efforts will streamline sustainability efforts with customer expectations.*** This approach will reduce redundant requests for sustainability metrics and provide a balanced way forward that includes producers in the developmental stage, thus ensuring that the process is not overly cumbersome. The request for such information continues to grow despite down economies, suggesting a resilient and long-term commitment by customers to developing such programs. In reality, this is consistent with the continually evolving agricultural systems across the United States, owned and operated by producers who are committed to the economic, environmental, and social well-being of their land and communities.

***NISA will result in a communications conduit to customers and the general public that has been significantly missing for agricultural producers.*** Industrial sustainability efforts have successfully focused on communicating improvements over time. Agriculture has yet to develop such a plan or communicate the gains already achieved by producers in typical sustainability parameters. The assessment-based approach, combined with appropriate outcome-based programs and a solid communications effort, will deliver a message of long-term commitment to sustainability by agricultural communities.

***NISA will address the entire farm, and not require multiple assessments for the diversity of crops produced within the farm gate.*** This approach will improve the efficiency of assessments, account for the complex interactions among crop rotations and livestock enterprises, and emphasize the environmental and social value of land on the farm not in production.

***The NISA business model is simple:***

- Educate.
  - —NISA will support the development of new crop- and region-specific sustainability programs through sharing of education, research and design. New and existing sustainability-assessment tools may be incorporated into a whole-farm program as appropriate to eliminate redundant questions and meet customer needs.
- Validate.
  - —Independent, expert advisory panels will inform and validate the assessment survey process on a crop- and region-specific basis. This effort will not only ensure the research basis for sustainability practices, but also gauge the process against customer expectations.
- Harmonize.
  - —The results of crop- and region-specific sustainability-assessment programs will be communicated to the supply chain and others within a common framework of expected outcomes, thus allowing agriculture to account for advancements in social, environmental and economic sustainability parameters through time.

While the formal NISA efforts are rather new, the initiative has attracted significant attention and engagement from numerous food-, feed- and fiber-producer organizations and others in the supply chain. Leaders are currently implementing a lean and nimble organizational structure that will achieve the business model and allow agricultural producers to reasonably assess sustainability and resource use, such as water, and report on advancements through time to customers and consumers.

## Potential Improvements from a Biotechnology and Sustainability Standpoint

The ultimate goal of sustainability endeavors is to *consistently* improve output per unit of input in response to global population growth. For example, fuel use in potato production and processing may be expressed as liters of diesel per bag of potato chips. Several of the input-per-unit-of-output measurements commonly used in agricultural sustainability could be addressed in part by advancements in crop biotechnology (Table).

## Conclusion

In a broader and often less-popular sense, great strides could be made in sustainable natural-resource use from agricultural and societal standpoints with a few relatively simple choices. From an agricultural standpoint, if the goal is to reduce water use and crop yield is improved through biotechnology and innovative practices, then land should be taken out of production. Using the same amount of a resource such as water to produce more will

*Table. Examples of agricultural sustainability goals and related output per unit of input parameters.*

| Agricultural sustainability goal | Output per unit of input parameter |
|---|---|
| Drought tolerance | Crop yield/liter of water |
| Nutrient-use efficiency | Crop yield/kilogram of fertilizer |
| Pest tolerance or resistance | Crop yield/kilogram of pesticide |
| Increased plant density | Crop yield/liter of fuel |
| Crop recovery, waste reduction | Crop yield/hectare |
| Nutritious crops | Human nutrition/calorie |

address some of the needs of a growing population, but will not address the limitations of that resource. From a societal standpoint, we can address a good portion of agricultural water use by simply not throwing our food away. As Jonathan Bloom points out in *American Wasteland* (2010), those well beyond the farm gate can play a significant role in conserving water resources as it relates to food production. Agriculture is the greatest user of water in the United States. Some experts estimate that up to 40% of the food produced is never consumed, and much of this waste ends up in the home garbage.

The first steps, however, are to adequately document and assess advancements in agricultural sustainability over time in a way that accounts for differences among regions and commodities. This needs to be done in a manner reasonable for the producer, consistent with expectations of others in the supply chain and through a process that is itself not burdensome. The National Initiative for Sustainable Agriculture provides an opportunity to meet these goals.

## References

Bloom J (2010) American Wasteland: How America Throws Away Nearly Half of Its Food (And What We Can Do About It). Cambridge, MA: Da Capo Press.

Federal Trade Commission (2010) News Release. http://www.ftc.gov/opa/2010/10/greenguide.shtm.

Grocery Manufacturers Association/Deloitte (2009) Finding the Green in Today's Shoppers: Sustainability Trends and New Shopper Insights. http://www.gmaonline.org/news-events/newsroom/more-than-half-of-shoppers-consider-product-sustainability-attributes-in-pu/.

International Food Information Council (2010) Consumer Perceptions About Food Technology. http://www.foodinsight.org/Resources/Detail.aspx?topic=2010_Consumer_Perceptions_of_Food_Technology_Survey.

Keene A Mitchell P (2010) Economic Impact of Specialty Crop Production and Processing in Wisconsin. Madison: Department of Agricultural and Applied Economics.

Kraft GK et al. (2012) Irrigation effects in the northern lake states: Wisconsin central sands revisited. Ground Water 50 308–318.

Weber C Matthews H (2008) Food miles and the relative climate impact of food choices in the United States. Environmental Science and Technology 42 3508–3513.

As director of Agricultural Systems Programming for the College of Agricultural & Life Sciences at the University of Wisconsin-Madison, JED COLQUHOUN provides leadership for the Wisconsin Institute for Sustainable Agriculture, the Environmental Resources Center and the Integrated Pest Management Program. His work on sustainability focuses on the intersection of food-production systems and environmental challenges, such as water quantity. Dr. Colquhoun also provides leadership for the National Initiative for Sustainable Agriculture, a producer-led, research-based framework for assessing agricultural sustainability at the farm level and communicating advancements in agriculture. He also has a faculty appointment in the Department of Horticulture and holds the Gottschalk Endowed Chair. Colquhoun received his BS and MS degrees from Cornell University and his PhD from the University of Wisconsin-Madison. Prior to returning to Madison, he was a faculty member at Oregon State University.

# *Preparing for Future Challenges of Water Issues*

Q&A[1]

Moderator: Jennie Popp
*University of Arkansas*
*Fayetteville, Arkansas*

Jennie Popp: For two days we have talked about agricultural biotechnology and water. What are the take-home messages from your presentations? In short, what is the prospect for agbiotechnology to address water issues in the future?

David Zilberman: I didn't address water specifically, but a key point is that, through agbiotech, we are able to produce more per unit of input. Any technology that increases yield, for example by pest control, is affecting water positively. A lot of people say we need drought-tolerant varieties. That is true. Improved drought tolerance is important, but by improving pest control we save water. If the overall performance of the system is improved, then water will be saved. If we have less waste, water will be saved. When we look at something like water we have to look at the direct effect, which is a technical challenge that, I think, agbiotech will be able to solve in time. However, agbiotech has already drastically improved the efficiency of inputs, including water.

[1]Some of the audiorecording, from which this written record was prepared, was of poor quality, rendering it impossible to accurately represent dialogue. Every effort has been made to provide a faithful transcription.

Reagan Waskom: David gave a great answer from a macro perspective, so let me share my thoughts on the micro perspective. One of the points I tried to make during my talk is that drought tolerance and water productivity are two different things. They get confused a lot, and I think they get confused in the biotech discussion in particular. When you are breeding for drought tolerance you are breeding for that ability of the plant to "hunker down" under drought conditions to reproduce later, or wait or to get through it, so to speak. Drought tolerance is different from breeding for more productivity per unit of water. And so David's point of view of more productivity out of that unit of water is really important from the macro scale and the question is can you confer those traits on plants genetically in an inheritable way. That's a more difficult and interesting question because these don't tend to be single-gene traits. These are multi-gene, complex traits that get you to water-use efficiency—if you want to use that term—or even drought tolerance. I like this question because I think that there is a lot of over-promising in the biotech sector. I run into people all the time in water circles and in ag circles who think that biotech is going to solve water problems in agriculture. I'm sorry, but I have yet to see that and I think we should under-promise and over-deliver rather than the opposite. I won't say that we shouldn't continue to pursue both drought tolerance and water productivity, but I think we need to be realistic about the way plants work and what it is going to take to get us there and to increase food productivity. I had the privilege of sitting on Monsanto's water-advisory committee for a couple of years and watching them in their development of the so-called drought genes, and Colorado State University has gotten to test those lines. We've got plots going. I can't show you the data, but the results of the first gene are very incremental. Can they get to a second gene? Can they get to multi-genic? Can they package this in a way that really gets a more water-efficient plant? I don't know, but I think we can get to overall greater productivity and I think that is maybe a better breeding target.

Zilberman: I agree. We need to under-promise and over-produce, but I think we also have to recognize what we have done. And we have already increased the productivity of water. I am responsible for assessing drought tolerance for the Gates Foundation and the thing that drives me crazy about Gates is that they want to have drought tolerance where the impact would be minimal. With *Bt* corn in Africa they can solve the water problem and other problems immediately. The key issue is not solving drought tolerance. What you really need to do is to increase productivity of available natural resources. If you have less pest damage, automatically water-use efficiency increases. Achieving drought tolerance is challenging. We have to first pick the low-hanging fruit and show to people what we have done. We haven't shown people that we have actually achieved a lot with GMOs. We don't need to wait until we have better ways to save water. What we have to do is to improve productivity of agriculture and then see what are the benefits.

Waskom: We are trying to figure out how to cut water use in crops and to grow stressed crops. What happens when you put crops under stress? Spider mites and aphids and stalk rot, right? Bad things happen. Plants do respond, but, if you put a plant under stress, things attack it. This is another aspect of this water-use efficiency question.

Jed Colqhhoun: The other two speakers have summarized it well, but just a couple of closing points on that question. First, the slide showing the Colorado River and the demand for water versus the supply over time is revealing. If you look at the gap between supply and demand, the magnitude of the problem there—and in other places—is too great for one solution. I agree that some of us see biotechnology as the silver bullet that will solve all of our problems. I also agree that the pieces that biotechnology brings to the table to improve production can be a component of that solution, but the magnitude of the problem is just too great at this point to rely on that. Gains are to be made in improving the recovery of what we produce in agriculture after it is produced, whether it be the efficiency of feed for example, whether it be recovery of corn products. Think about the recovery rate on corn, the grain versus the rest of the actual plant. It's still pretty low. We leave a lot in the field at this point if it's not silage. Also, perishability is a factor—allowing more of what we produce to be used may be a backward way to attack this problem, but it may get us a lot farther than tackling individual components using biotechnology.

Rick Bennett (University of Arkansas, Fayetteville): Dr. Zilberman, you showed some data that indicate that GM crops would have a greater impact on productivity in Africa and developing countries than in the developed countries, and I think that part of your explanation is that using GM crops free them up to use more pesticides. However, GM crops are not planted very much in Africa. Africa has been pretty much excluded from agbiotech because they can't afford to plant GM crops. Have you or anybody else done an economic analysis of the benefits of GM crops in Africa versus the cost of food aid? Because somebody is going to feed Africa. If Africa can't feed itself, North America—Canada, the United States—and Europe will have to step in and feed Africa. Do you know what the analysis is of food aid versus planting GM crops?

Zilberman: The issue is not affording it. There are two main constraints. First is the regulatory system. In Africa there are complex regulatory systems that make it difficult to introduce new GM. This regulatory system is excessive and unjustified. Secondly, the political decision has been made in many African countries not to allow GM because they are connected to Europe. They are influenced by Europe. Europe has much more to say in Africa than we have to say. We have an organization in the United States, PIPRA, Public Intellectual Property Rights for Agriculture, which collects all intellectual property of universities on GMOs and you can move it to an African university and you can introduce it there. So the big issue in Africa is not cost. The big issue in Africa is regulation. Either safety regulation that can be done if someone would invest in it, but I think in many cases is redundant. More importantly, African nations want to go with Europe and ban it. There are many examples of the effective adoption of GM in Africa. Burkina Faso, one of the least developed countries in the world, adopted *Bt* cotton and increased farm profitability by 60% by increasing yields by 70%. South Africa has one of the most advanced adoption of GM. It has increased yield drastically and it is profitable. Tomorrow, if Gates decides to invest in *Bt* corn in Africa, he can invest in Ghana and other countries and it would be profitable. It will increase yield and it will do a lot of good things. Now my calculation is that if, tomorrow, you have adoption of *Bt* corn and soybean in Africa and Europe, it will have the same effect, more or less, as adoption of biofuel. Now, in Africa the problem is not only pests. In Africa the problem is that you need to use fertilizer, *etc*. But the yield effect of adopting GM in Africa would be so drastic that it would reduce price significantly. So, to me, the key issues are political. It is a public debate and a political debate rather than a technical debate. So, what happens is that people like Gates say, "Gosh, the African nations don't want GM. They are afraid of it because they are afraid of the Europeans. So we will bring them drought-tolerant varieties." I agree that drought-tolerant varieties would solve the problem. There are lots of other things that GM can solve. It was mentioned that you can improve the digestibility of soybean. That is something that we know is available, but no one has investigated it because people are afraid of it because of the political environment. To me, the key issue today is the image that GM is not sustainable, not good for the environment, *etc*., whereas we have evidence now that already GM helps the poor by reducing prices and the global environment by saving land and it saves water and in Africa it can save aid, reduce prices and increase water-use efficiency. The issue is political.

Ralph Hardy (National Agricultural Biotechnology Council, Ithaca) Dr. Zilberman, in May of 2012 an organization called PG Economics Limited, based in the UK, published a 187-page survey called *GM Crops, Global Socioeconomics and Environmental Impacts*, covering the period 1996 to 2010. It's a heavily referenced document. It made statements like, "Since 1996 the cumulative increase to farm income from GM technology has been $78 billion." It divided this up into a number of countries. It provided the data for India and China where, in recent years, the major economic impact has been from *Bt* cotton. Should I have comfort with this document as a valid source of information or shouldn't I?

Zilberman: The document is not bad. The National Research Council produced a report about GM that included economic and environmental effects, and I feel better about that. The UK report doesn't take into account the impact of GM on food prices. GM actually increases the affordability of food, so, to some extent, they underestimate that aspect and overestimate the impact on the well-being of farmers. All in all, it's a decent report, but the US NRC report is better.

Steve Slack (Ohio State University, Wooster): Jed, this question is for you. The Central Sands is a very proscribed area. It's a very intensive well developed agricultural system. And you've laid out a lot of the variables. Could you describe how the agricultural industry is responding to some of these tensions and pressures and also whether or not NISA is playing any kind of a role in that, other than observational at this point?

Colquhoun: There are two pieces to that. Grower involvement has been very strong. Over the last couple of years, we have created what we call the Central Wisconsin Ground Water Task Force. In the past year, the Task Force has integrated municipalities, industrial water users and, most importantly, the lakes associations and river alliances in that area to work together towards finding some common ground. We have involvement also, as I mentioned, from folks like Trout Unlimited and Ducks Unlimited. This is a community-based problem. The Wisconsin Institute for Sustainable Agriculture's effort is to help provide on-the-ground solutions, but not tell people what their communities should look like. We have worked very hard to maintain that with this particular issue. It is an opportunity for play-space learning and experiential learning for our students, but we are looking for the community to work together to find common ground. Some very creative pieces have been put forward that would at least be interim solutions that involve the growers assisting the lakes associations. For example, the growers have, out of their own pockets, recently invested heavily in well-monitoring technology—monitoring the water levels in these high-capacity wells every 15 minutes around the lakes of concern and such. Very interesting information has already come out of that; the water levels in the wells around the lakes are actually higher than the lake level—much higher—by 15 feet or so in some areas. So, something else is going on in this picture and that's where community involvement comes in. Little Plover River—growers have been filling the headwater of that river for over two years, just to keep the water running as an interim solution to keep trout in the river. They pump out of their irrigation wells into the headwaters of the river. Is it a long-term solution? Of course not, they realize that. But they are at the table with the community, to assist in moving forward. In terms of NISA itself, again it comes down to pieces like measuring water levels in wells. How do we do that in a reasonable way? How do we determine evapotranspiration in a changing-crop scenario and crop rotations where we are growing shorter-season crops with more shoulder seasons—spring and fall—with no crop on the land? How do we assess the impacts of that related to parameters like water? This is where NISA steps in with reasonable assessment programs to try to document baselines, show improvement over time through some of this work and report back against that to everyone from the consumers and the lakes associations and also to the value chain and the purchasers of those products.

Rick Bennett (University of Arkansas, Fayetteville): Reagan, you mentioned that stream flows across the Ogallala Aquifer are not replenished by the aquifer. Is that correct? And you went on to say that, as the aquifer declines, the stream flows decline. I'm asking the question because, obviously, farmers are pulling water off the rivers that cross the aquifer. I'm not quite sure I'm understanding what is happening there.

Waskom: It's an interesting scenario because those streams pick up rainfall. They are not snow-melt driven, they are precipitation-driven streams. But, as they came across the aquifer, historically they were known as gaining streams. It's complicated because there is usually the Alluvial Aquifer and then there is the regional High Plains Aquifer with a connection between them. But as we draw down the High Plains Aquifer, the Alluvial

Aquifer starts to feed it, which draws the stream down. It's a cascading effect. So, yes, those streams were gaining from the Ogallala Aquifer, or the High Plains Aquifer indirectly. Kansas recently sued Nebraska and Colorado got implicated in that on the Republican River as well. So now we are in the painful process of the pullback and this is why the title of my presentation was about optimizing water for food, environment and cities. I didn't use the word sustainability because we're not even close to sustainability. We have over-allocated almost all of the surface and groundwater systems in the west. We have a long way to go. Right now we're in an optimization mode with respect to putting 9 billion people on this planet. We are going to have to reset the bar for what is sustainability. We will come back around to this later when we have withdrawn these aquifers and we have taken that agriculture out of production and we are still feeding those people. We are in a chaotic realm right now where we realize the connection. It took us a long time to get into this problem—50 years of slow, incremental, over-allocation of these systems. Our models show us what's happening out there, and it's going to be turbulent. It's going to be really tough on producers. Federal support can soften the landing only to a certain extent; some producers are already crash-landing.

Zilberman: What do you think about the use of urban wastewater to increase supply?

Waskom: That's a great question. The prospects for reuse are important for us to investigate in agriculture and many repercussions ripple out from them. In places like Colorado's Front Range, urban growth is occurring on previously irrigated land. We are substituting blue grass and houses for corn and it's amazing. An acre of 4 or 5 houses and bluegrass is about equal to an acre of corn. It's a complete substitution, but what is starting to happen now, of course, is we are having to reach further and further into agriculture to get water to sustain growth. So sustainability is about sustaining growth, but not food in that particular case. The prospect for agriculture to provide this service—we haven't heard the term ecosystem services—of assimilating society's waste and profiting from societies waste is a rich area for consideration. We are looking at it in Colorado. In Florida and California a lot of work has been done in water reuse because of their discharge standards. Their discharge standards got so difficult that they began to reuse in the Central Valley and in Florida because it was cheaper to do that than to put that wastewater flow back into the stream. A lot of the other western states haven't gotten there. Urban conservation, ag conservation, reuse, markets—we haven't talked about water markets—there is huge potential in terms of efficiency, in terms of allowing some fungibility about the way water moves across systems and across states and basins, which can help producers become profitable. That may be spoken with more of a western point of view than an eastern, but I think all of these are things that academia can bring a lot to. And crop breeding is part of it because that reuse water is higher in salinity. It's higher in sodium. It's got a lot of stuff in it. We've got to figure out how to utilize that, break it down, assimilate it, *etc*.

Zilberman: The issue of water marketing—all of California is based on moving water from A to B and it increases productivity immensely. For the last 30 or 40 years, we haven't allowed water trading so one reason that people don't adopt more advanced irrigation is that if you save water you lose water rights. That is very important. Even in Florida you have a situation where people don't adopt even a low pressure center pivot because of the fact that they cannot trade water. In California they moved 10% of the water from agriculture to environment and increased productivity of water quite significantly because of water trading. So, this is another solution that I think is really important.

Waskom: Yes and I might mention Oregon passed a saved- or conserved-water statute where institutions and organizations can upgrade their systems and conserve water. They have to put half of that water back into environmental flows and the other half of that water is available for fungibility, for markets and trading. And that has stimulated some really neat solutions around salmon in Oregon by a simple change of the law, and things cascaded from there. It doesn't fix everything, but, again, it's an example of how institutions and markets can drive change.

# PART IV—BANQUET PRESENTATION

# *Water for Food: Everyone's Challenge*

Marc Andreini
*University of Nebraska*
*Lincoln, Nebraska*

mandreini2@unl.edu

In the United States we have tremendous potential as a result of high yields and large-scale producers. There are 47,400 farms and ranches, and 18.4 million hectares of farmland. The western part of the US corn belt produces more than 40% of the world's corn and soybean, which, sometimes, we take for granted

Despite problems and concerns, including increasing demands for food globally, we assume that what we are doing will be sustainable. There's a sense of stewardship among farmers in Nebraska, and, I suspect, elsewhere in United States, and we expect that high yields will be maintained—even in the face of major shocks—and that our agricultural practices will have acceptable environmental effects. We know that climate change will have an impact, but, because we are resilient, there is the expectation that we will keep producing and feed ourselves.

## Population and Productivity

Figure 1 shows expected population increases globally until 2050; 49% of the increase will occur in Africa and 41% in Asia. Numerically, there will be a lot more people in Asia than in Africa, but given relatively poor access to resources, it is important to remember that both of these regions will experience stress.

Figure 2 shows anticipated annual productivity increases that will be needed to double output. Why will output need to be doubled when the population increase will be approximately 50% (Figure 1)? The main reason is that, as people become more affluent, their food expectations change. Particularly in India and China, people will expect to eat more expensive diets, including more meat. Also, we have to worry about land resources.

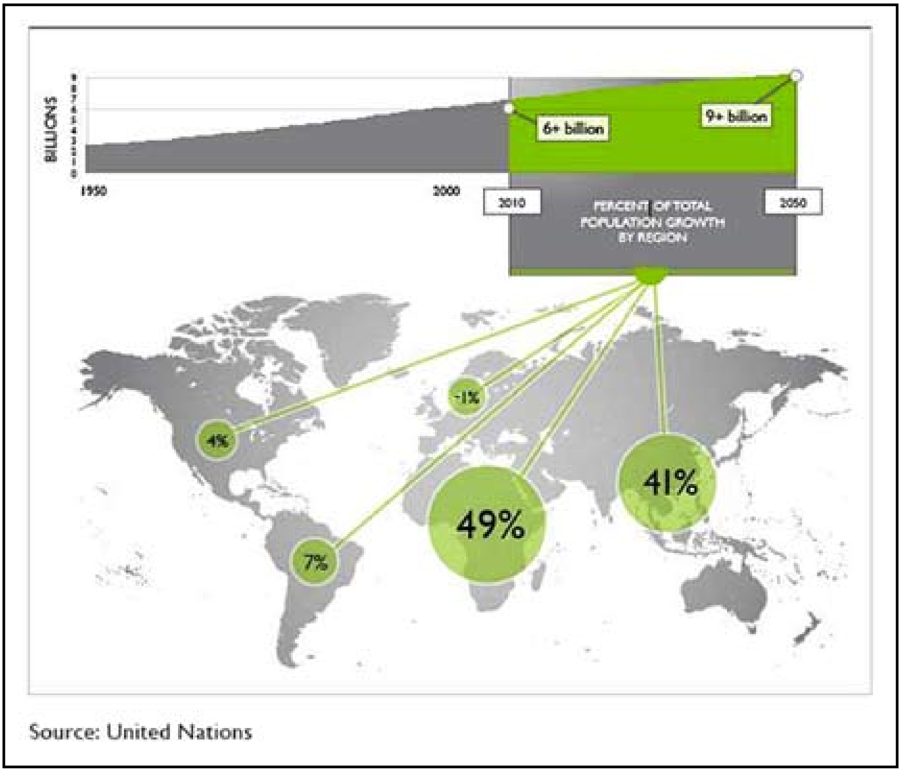



Figure 1. Population growth by region (2010–2050).

Figure 3 shows that the fraction of land area devoted globally to agriculture started leveling off in the 1990s. Africa is the main spot where arable land remains uncultivated. On the other hand, there is concern over loss of biodiversity that may result from uncontrolled expansion of agriculture. Figure 3 also shows cultivated hectares per capita; currently there are only 0.7 hectares per capita, 50% of what was available 50 years ago, as the population continues to grow.

FAO data for 2009 indicate that, in Asia, only 0.13 hectares of arable land are available per capita, whereas Oceania (which includes Australia, much of which is too dry for farming) has 32 hectares of arable land per capita. Africa has 0.31 hectare per capita, and so is in better shape in terms of land resources than is Asia.

## Unsustainable Water Usage

Global crop-water demand has grown linearly since the 1960s, and doubled between 1960 and 2000 (Figure 4). One area of concern is increased use of non-renewable groundwater, *e.g.* groundwater mining in the southwest of the United States. However, there is a larger issue in India, particularly in the Indus River plain where groundwater is being mined. Half a billion people depend on food from that area and the groundwater is a finite resource

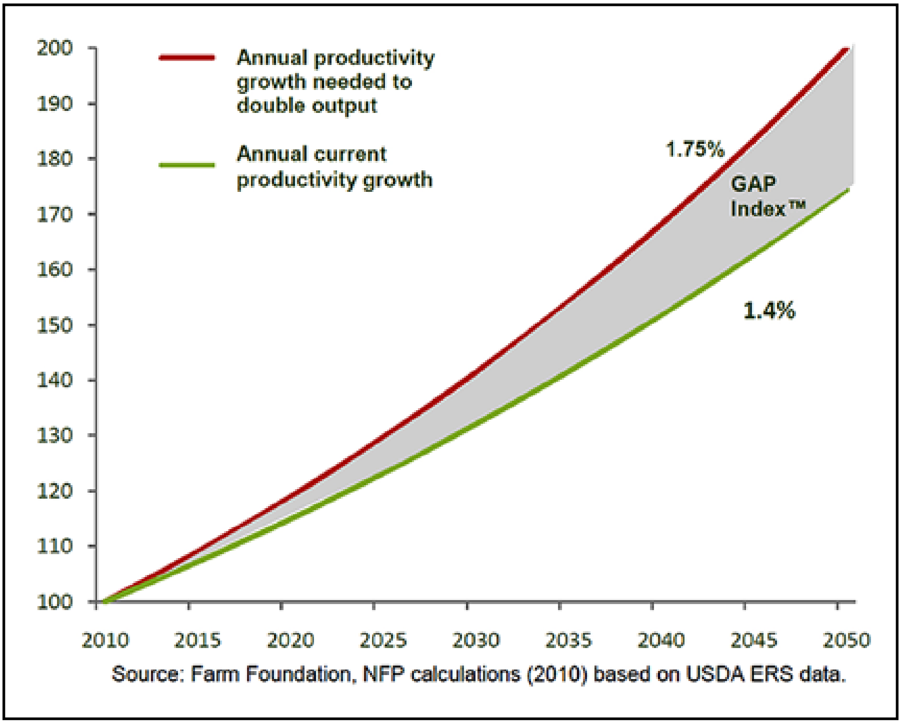



Figure 2. Productivity gap.

that is disappearing. Similar unsustainable withdrawals of groundwater are occurring in China. Therefore, not only do we have to improve water productivity, but we have to achieve it with diminished resources.

FAO data for water usage show that huge amounts are used for agriculture in Asia, and relatively little in sub-Saharan Africa. In Asia, many of the basins are closed and extensive infrastructure has been in place for thousands of years, mainly for cultivation of rice, a water-intensive crop. Africa has significant water resources. There are several major rivers but little withdrawal from them.

Figure 5 provides a water-scarcity map produced by the International Water Management Institute, showing two different types of scarcity:

- absolute physical water scarcity, and
- economic water scarcity

Physical water scarcity is a ratio of how many cubic meters fall on a country or area compared to the number of people inhabiting that country or area. Across North Africa and through the Middle East there is absolute physical scarcity. Economic water scarcity affects more of the globe; it is a measure of the ability of people to withdraw water from the system. It doesn't have a direct bearing on what is available, but indicates lack of infrastructure necessary to use water. And in some areas like the Sahel—the zone below

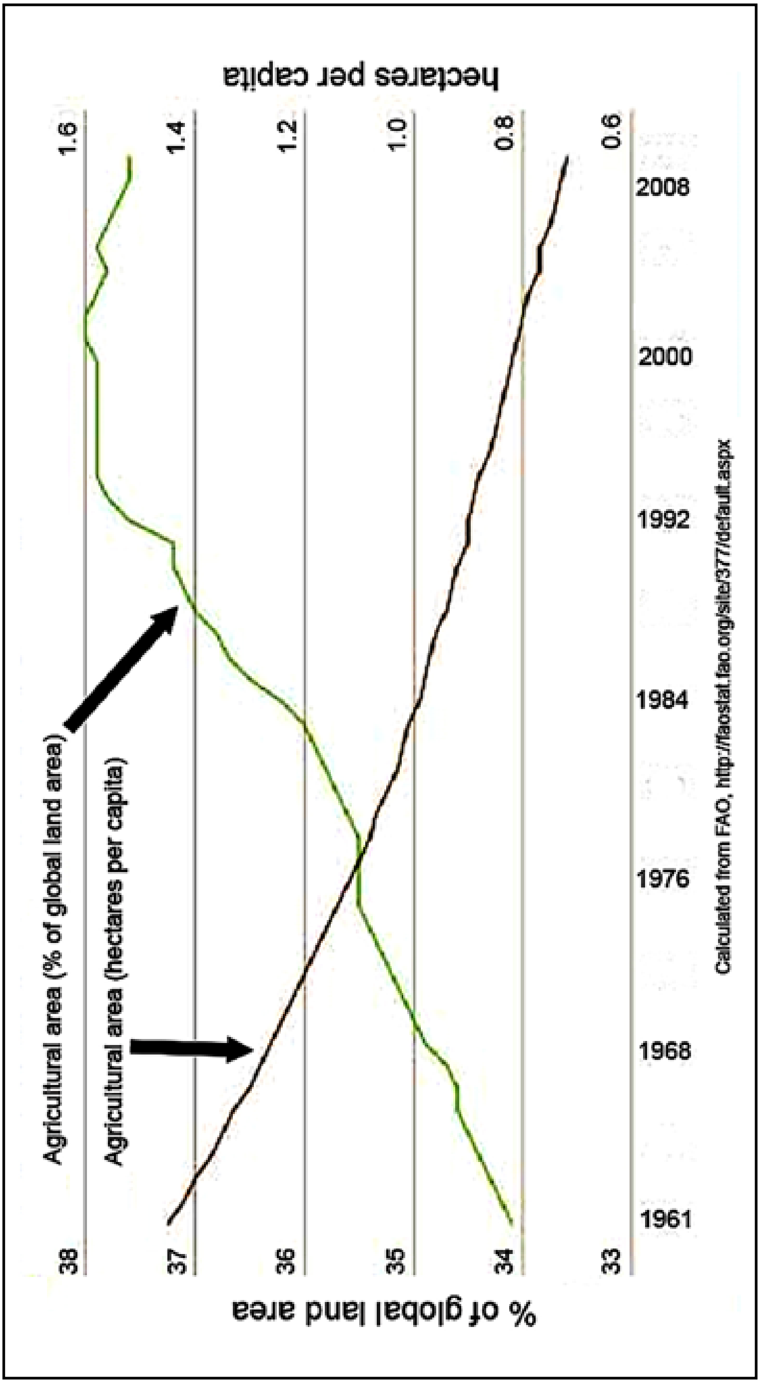



Figure 3. Land used for agriculture

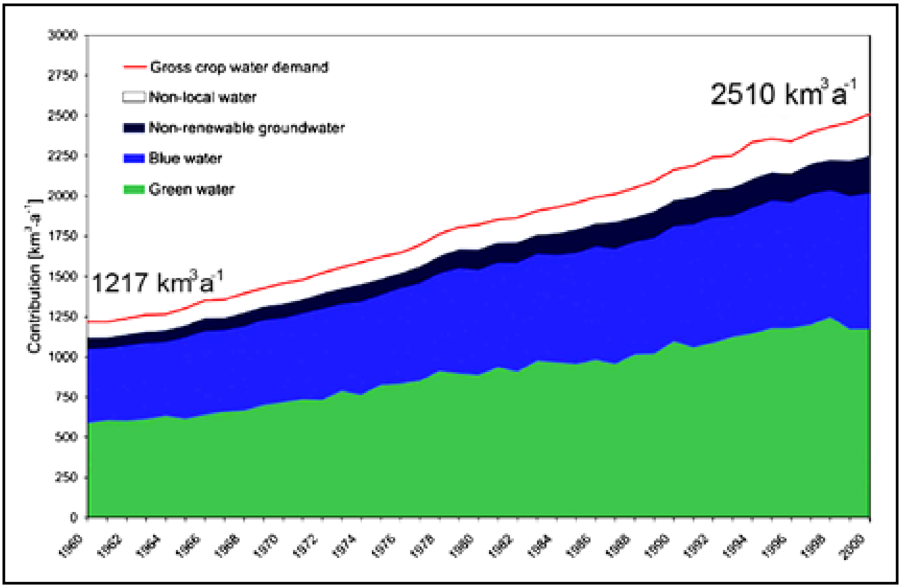



Figure 4. Global gross crop-water demand

North Africa—there is physical as well as economic water scarcity. Figure 5 reveals how dire the situation is in many parts of the world.

## Second Green Revolution

The Green Revolution occurred in the late 1960s and early 1970s. Although controversial, there is no doubt that millions of people were fed. Jacques Diouf, director general of FAO has stated:

> *Science and technology must spearhead agricultural production in the next 40 years at a pace faster than the Green Revolution did during the past three decades.*

In Asia in particular, people talk about a second Green Revolution. The first Green Revolution was built on a hydraulic base; irrigation systems were already in place. Yield improvements had a lot to do with the development of input packages for rice. Africa was and remains a different situation in that the infrastructural "backbone" is still not in place. Addressing food-scarcity will be more of a challenge in Africa. Its heterogeneity will require a greater diversity of inputs.

There follow unrelated issues to provide background for discussing Africa:

- Stationarity is dead.
- Africa is a heterogeneous environment.
- National food security and agriculture are drivers of economic growth.
- Policy and practice.

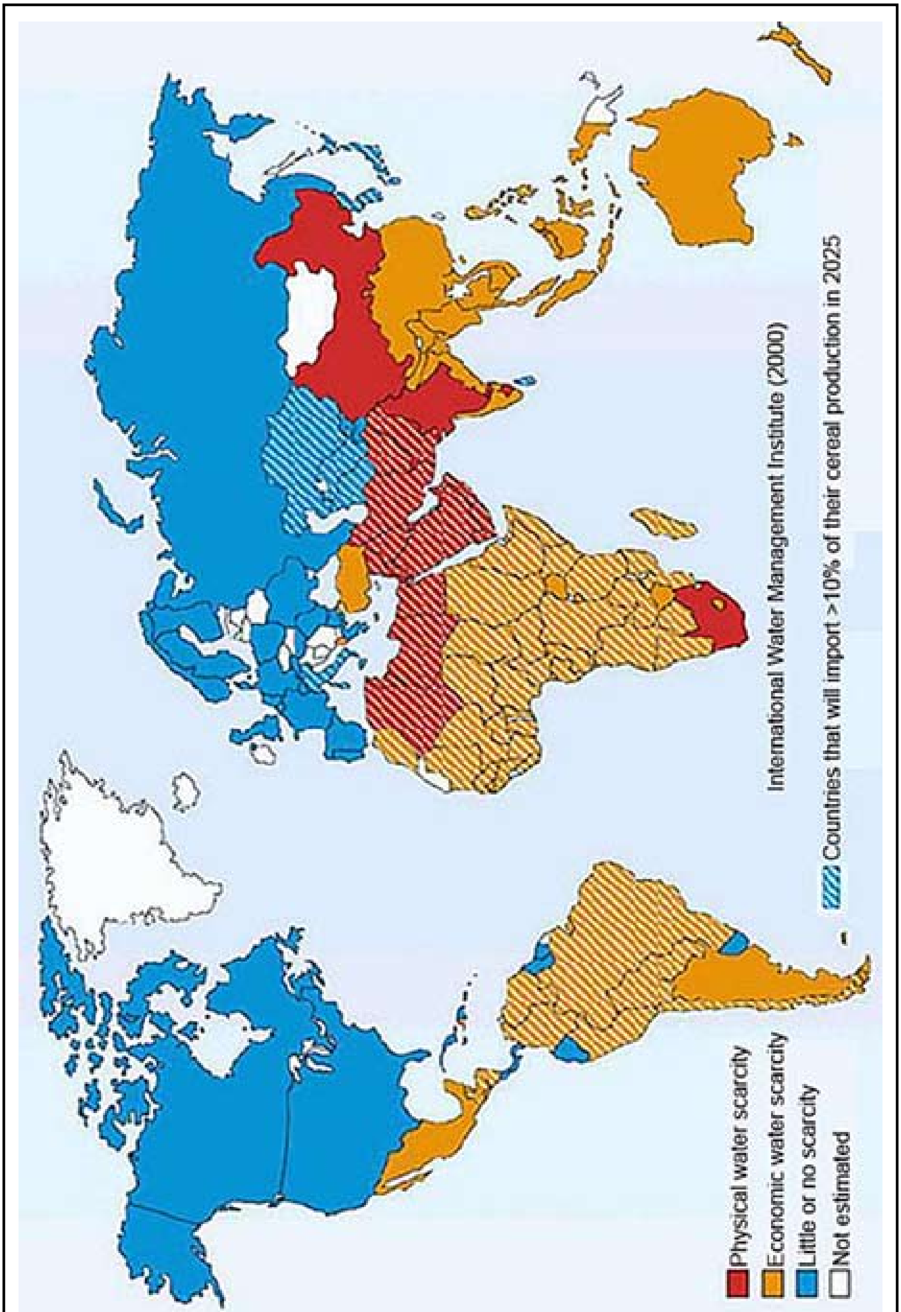



Figure 5. Physical and economic scarcity of water.

First of all, there is every expectation that stationarity is dead. In other words, what happened with rainfall last year, or even over the last 40 years, is not necessarily what we can look forward to. We are pretty sure that the planet is warming, but the implications in terms of water resources or river flows, even in the most basic sense, are poorly understood. We know that there will be more evaporation from the ocean, but it is uncertain whether that will result in more rainfall or drought.

Secondly, and extremely important, Africa is a very heterogeneous environment. I mention this because when we study something, we tend to become an advocate for it. When I studied small reservoirs I began to see utility everywhere in small reservoirs. As an engineer, I am interested in irrigation-water management, but part of me knows that rain-fed production is extremely important. In fact, it's a case of "horses for courses." In one country or region, emphasis should be placed on rain-fed production, whereas in another country or region increasing rain-fed production may mean chopping down forest and destroying biodiversity. All possible options should be carefully considered when we address problems.

In Africa and globally, there is a lot of discussion of virtual water. In other words, if we are in Nebraska and can produce corn inexpensively, by selling that corn to other countries we are exporting water. That radical policy construct is a valid consideration, but it's also important to remember that each country wants food security in and of itself. Also, if you are a farmer in Burkina Faso—where it is difficult to grow corn or anything else because of rainfall uncertainty and frequent lack of rain—that doesn't mean that there are options, such as moving to the capital city to work on computers. In other words, farming is often the only option and we should be giving our attention to farming under stressed conditions and thinking less about virtual water other than as a policy construct. The other thing is that agriculture has been and will continue to be the economic driver of growth in Africa.

Finally there's a great deal of emphasis on policy and, as far as Africa is concerned, I have a jaundiced view of policy because many African countries already have well written, enlightened policies in place. However, they don't extend too far past the agriculture ministry's front door. In other words, marrying policy with practice is a far more difficult task than just writing new policy.

Africa experiences extreme spatial and temporal variability in rainfall even without the weather extremes that are likely to occur as a result of climate change. Figure 6 shows women collecting water in head pans and carboys from a hand-pump. Most of the vessels remain empty because pumping is slow; it's the dry season and the water table is low. A sudden, heavy downpour causes the women to employ empty head pans as umbrellas.

Given this variability in rainfall, the need for storage and infrastructure is clear. Figure 7 emphasizes that although Africa has much arable land, very little is irrigated and very little of it is accessible to transport. A great deal of attention is being given to value chains and market access, so roads and water-related infrastructure are of primary importance, and, accordingly, investment is needed.

Data from the World Bank reveal that North America has more than 6,000 cubic meters of water-storage capacity per capita (Figure 8), whereas South Africa, which has

Figure 6. Dry season in Africa: an illustration of rainfall variability.

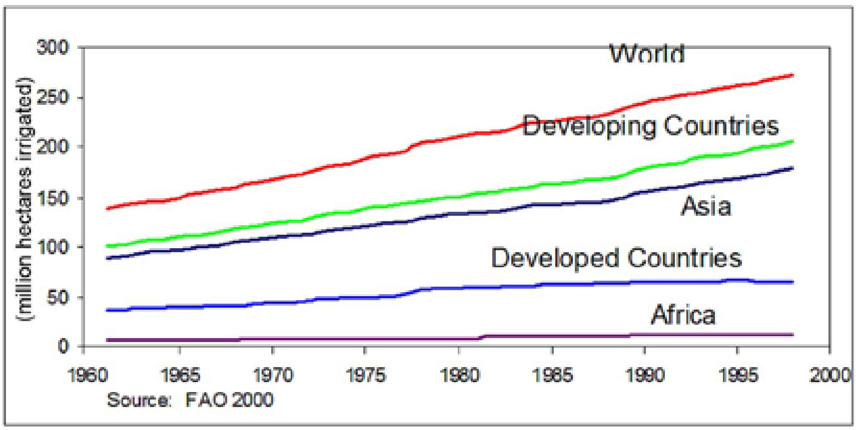



Figure 7. Africa lags in irrigation infrastructure.

the most infrastructure in the continent of Africa, has just 750 cubic meters per capita. Ethiopia and Kenya are next with 43 and 4 cubic meters per capita, In short, there is very little by way of large or medium infrastructure in Africa.

What does this mean? You have variable rainfall. You have a largely agrarian society with a limited industrial sector and you have very little water-related infrastructure to buffer rainfall variability. Figure 9 shows how closely agricultural GDP growth tracks with

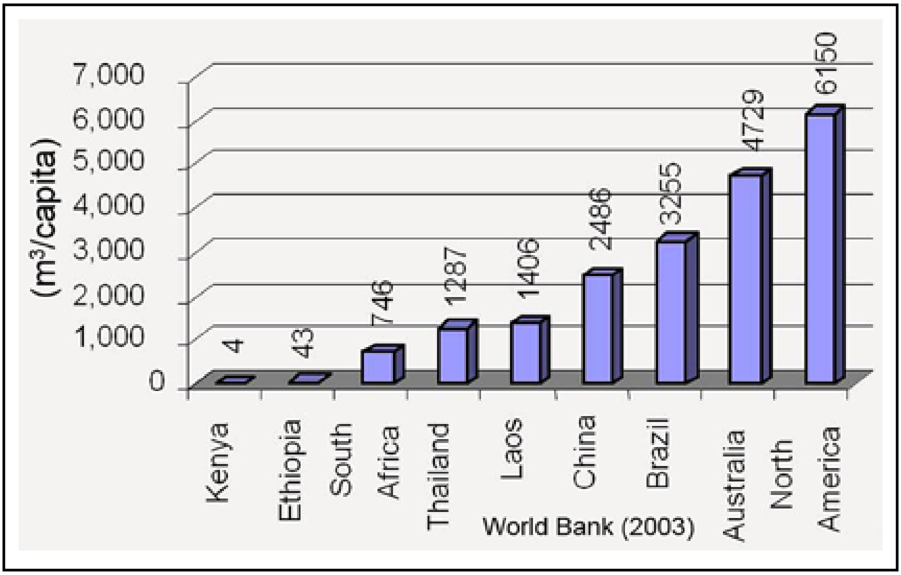



Figure 8. Water-storage capacity.

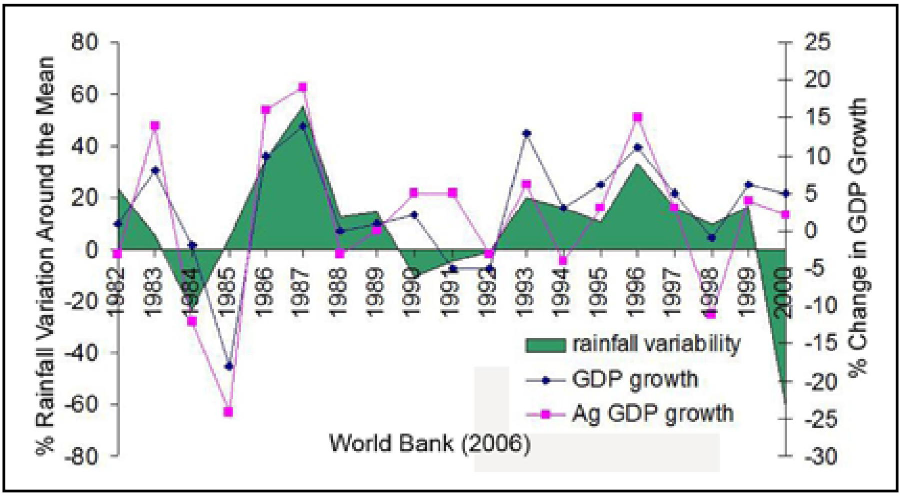



Figure 9. Impact of rainfall variability on GDP and agricultural GDP growth in Ethiopia.

rainfall for Ethiopia. When precipitation is above the norm, growth goes up, and when it is below the norm, growth goes down. This is not a surprising outcome. To reinforce this point, Figure 10 shows similar data for Kenya. (The correlation is not as strong as for Ethiopia, in part because Kenya's economy is more diversified and the populace slightly more affluent.)

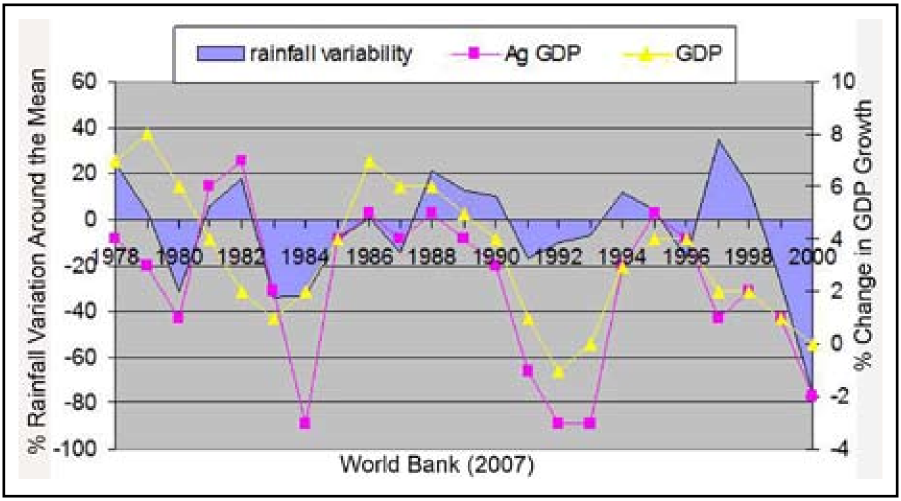



Figure 10. Impact of rainfall variability on GDP and agricultural GDP growth in Kenya.

What needs to be done to increase food production? This gets back to my point that we need to consider all options and not become fixed in our way of thinking. We can bring more dry land into production. Areas of Angola, for example, have perfect weather and fertile soils, with the potential to feed the whole of southern Africa. Yields of rain-fed crops can be improved by manipulation of drought tolerance through plant genetics. Irrigation infrastructure needs to be improved. There are major rivers in Africa—the Niger, the Congo, the Volta, the Zambezi—yet there are only three or four large dams on the whole continent. The Akosombo dam (in Ghana) is on the Volta and two are on the Zambezi, the Kariba (between Zimbabwe and Zambia) and the Cahora Bassa (Mozambique). Some construction is in progress in Zimbabwe and South Africa, but, in general, there is plenty of opportunity.

In the 1980s there was backlash against building infrastructure for a couple of reasons. Costs became enormous, some of which was real and some occurred due to lack of transparency. And pressure from environmentalists on the World Bank, and other factors, resulted in withdrawal of investments in those areas. We have learned lessons and we need intelligently designed infrastructure. We need to look at environmental studies and the active issues and to provide appropriate compensation for people who are disadvantaged. In other words, do it right and not leap forward blindly, and thus improve yields through irrigation.

## Water for Africa

I'm making the argument that, for Africa, we need more instruction. How is a reliable supply of water to be achieved? First of all, storage and delivery infrastructure has to be built. Secondly—and this is extremely important—secure water rights are needed. Thirdly, farmers everywhere are risk-averse but, with a reliable water supply, they may invest in more equipment, in more inputs and in improved seeds. Much of the behavior of small-scale farmers in the Sahel and southern Africa is rational in terms of the conditions they face. If they make a crucial mistake it may be literally fatal. I posit that they are smart and manage as best they can, but with better water supply they could make more investments and perhaps significantly increase productivity.

What are the options? As said, large dams are expensive, they take a long time to put in place, and they come with a lot of institutional overhead—medium-sized dams likewise. Small reservoirs are a good option. In many places, no groundwater is available. Where I was working in northern Ghana and southern Burkina Faso, there are thousands of small community-managed reservoirs. On the other hand, the institutions required for efficient running of these reservoirs are often poorly developed. One reservoir may be efficiently utilized for irrigation whereas another similar reservoir, just 5 kilometers distant, might be unused and baking in the sun. The reason is that this is an extremely heterogeneous environment. One may have been built by a program under which time was invested in teaching people how to farm in the irrigated perimeter, and the other may have been a product of the early "glory days" when people thought that everything was simple. There may be a million reasons why they don't work, requiring a lot of study to gain full understanding, but I am a firm believer that small reservoirs have a useful role. Boreholes are another option, but groundwater resources are poorly understood. We don't know with any certainty where they are or how reliable and sustainable their water yields will be.

Also an option, of course, is to build nothing and work with rain-fed production.

Achieving infrastructure requires responsible institutions to achieve financing, even for relatively humble projects. Tendering awards is a process rife with corruption and inefficiency. I worked on a large project in Botswana and well meaning local contractors would subcontract some of the smaller jobs for roads, housing and ancillary parts of the project, and I learned that some of these individuals were crooks, but a lot of them didn't know how to function as contractors. Some project leaders were skilled at working with them and teaching them; so instruction is a big issue and where the capabilities of subcontractors are limited, it's an area where there is enormous opportunity to improve.

When I was working in northern Ghana on a formal contract with the World Bank, building small dams, all of the specifications seemed in order. I asked, "Are any of these completed?" And the reply would often be "no," perhaps because a key worker had died in a motorcycle accident. It wasn't their fault, but there didn't seem to be any supervisory follow-up. Some of the dams were poorly constructed and collapsed after heavy rains in February of 2007. The thing I found most irritating was that maintenance responsibilities, and blame for failures, fell to the villagers, the clients, when the dams weren't well built in the first place.

Another thing to remember is that almost all water resources are multi-purpose. People swim in reservoirs, fish in them, and water their stock there. Even with a humble hand-pump water is used for ducks, small gardens, and other domestic activities; that's important. The agricultural intensification that comes with increased water availability has ecological consequences with negative implication for human health and downstream scarcity (Figure 11).

Figure 11. Agricultural intensification has ecological consequences.

Nebraska has a system of natural-resource districts (NRDs) based on watershed boundaries, which cut across political boundaries and have the power to levy taxation. However, it's a far cry from integrated water-resource management. One thing people forget is it's mostly about allocation. The British cleverly made a treaty among their former colonies, the Egyptians and, upstream, Kenya and Uganda, and allocated most of the water in the Nile basin to the Egyptians. This wasn't a fair way to do business and the countries involved are trying to renegotiate and manage the Nile better. Of course the important thing to remember is that populations in these and other countries fed by the Nile are now much higher, causing greater demands for water. They have managed to negotiate every single aspect of the treaty except allocation of the water, which has emerged as an extremely contentious issue.

In Africa there is usually no control over rivers because there are no dams and there is little removal. It is rarely a national priority. African leadership, which has been less than stellar, but is getting better, has things to worry about other than integrated water-resource management. A particular concern is insufficient data. A few weather stations, set up in the colonial era, are still operational, but, in large part, Africa is resource poor when it comes to precise weather information. There is increasing dependence on remote sensing of weather parameters, but, at some point, ground data are needed to calibrate the models. Also often ignored is the fact that stakeholders are illegitimate and/or poorly organized or not organized at all. Here in the United States, farmers are affluent and relatively well organized, as are water-utility workers and industrial users—not that they necessarily agree, but they are legitimate and relatively well organized. That's not true in African countries particularly regarding farmers. With maybe 4 or 5 acres apiece, they don't have the time or the inclination to be organized; they just don't have the resources.

## In Summary

*There are formidable challenges and together we can overcome them.*

This isn't a well worded or profound quote, but, although the challenges *are* formidable—as I have stated here—I do believe that if we work together, with collaborative research, then they can be overcome.

**MARK ANDREINI** has broad international experience, having been a water adviser for the US Agency for International Development in the Bureau for Economic Growth and Trade. His recent work has focused on small reservoirs—how they are used—and areas of research to improve the livelihoods of small farmers. Before joining USAID, Andreini was a senior researcher with the International Water Management Institute, where he was the Ghana coordinator of the GLOWA Volta Project and the leader of the Small Reservoirs Project. He has contributed to projects to strengthen basin-level integrated water management and address issues of water productivity. He has worked in California and several African countries and has been involved in a variety of water-management and supply projects. A professional engineer, Andreini has studied solute movement under conventional and conservation tillage, and shallow groundwater irrigation in Zimbabwe. He built village water-supply systems in Morocco, was a physical planner for the United Nations High Commissioner of Refugees in Tanzania, and was a member of the project-coordinating unit supervising the construction of Botswana's North-South Carrier.

Q&A

Rick Bennett (University of Arkansas, Fayetteville): A slide, with water-scarcity data, had all of the United States colored in blue. It probably represented the US in general. On the other hand, regional water issues exist in various parts of the country. You talked about the situation in Africa, and we have a similar situation here. Can we deal with this in the United States the way it's being dealt with in Africa?

Andreini: National statistics are always misleading. That's my first comment. Second of all, we have states and it's good that we have those smaller political units. Arkansas can deal with Arkansas' problems, because they know them and understand them. The Land-Grant system was one of the most far-sighted pieces of legislation ever and, as a result, we are much better situated to deal with a country as large as the United States than almost anywhere else.

Ken Korth (University of Arkansas, Fayetteville): Regarding GMOs and transgenic crops, when Africa is brought up in terms of helping growers and so on, people often object and say there's a conspiracy in agrochemical industry to suppress conventional agriculture. Do you run into that? When you make recommendations regarding infrastructure for pumping water, do you get that negative?

Andreini: Of course. For example, in the 1950s they built the Kariba Dam. At that time it was Northern and Southern Rhodesia, before the unilateral declaration of independence by Ian Smith. They saved the Tonga people who lived along the river with a resettlement scheme, with mixed results. Ghana did better with the Akosombo Dam, which produced Lake Volta, the largest surface area of any reservoir in the world and which displaced many, many people. Kwame Nkrumah made a real attempt to successfully resettle the native people and tried to do it right. The small holders who operated efficiently were bought tractors, *etc.*, and encouraged to farm collectively. It was a resounding failure. The good news was they were at least making an attempt and understood issues of equity and so on, but didn't do a good job. Particularly with water dams, you find these issues. A lot of the exported agriculture goes to Europe, and there is a great deal of fear, particularly in southern Africa that, if they grow GMOs at all, any contamination could cause the loss of their European market. The other thing is that the Africans often say that they've been hard done to. Colonialism is not ancient history and so, rightly or wrongly, they are suspicious of any sort of invasion from us. Although GMOs have positive contributions to make to Africa, it will take a while.

Graham Scoles (University of Saskatchewan, Saskatoon): Can you point to any success stories regarding irrigation?

Andreini: Burkina Faso, in particular, has a program building small reservoirs which seems to be well managed. In Zimbabwe in the early 1990s, they had something called Agricultural and Technical Extension Services and I did research on gardening there on small plots. At that time, AGRITECH had an extension worker for every several hundred households, and some of the supervisors were extremely patriotic, knowledgeable and highly motivated. That system actually worked pretty well. Things have changed under Robert Mugabe. Extension knowledge is extremely important. You see this in reservoirs in northern Ghana—where people have bothered to spend the time to get things going right—things are going much better than where a reservoir was built and then left. There is reason for optimism, that's for sure.

# PART V—STUDENT VOICE[1] AT NABC 24



[1]To encourage graduate-student participation at NABC conferences, the *Student Voice at NABC* program was launched ahead of NABC 19. Feedback from those involved was positive, therefore the program was continued for NABC 20–24. Grants of up to $750 are offered to graduate students at NABC-member institutions (one per non-host institution) to assist with travel and lodging expenses. Registration fees are waived for the SV participants. NABC-member institutions are listed on page v. *Student Voice* delegates attend the plenary sessions and breakout workshops then meet as a group to identify current and emerging issues relevant to the conference subject matter. Information on the *Student Voice at NABC 25* will be available in due course at http://nabc.cals.cornell.edu/studentvoice/

# *Student Voice Report*

Grace Richardson[2]
*University of Arkansas*
*Fayetteville, Arkansas*

Melissa Arkand
*University of Saskatchewan*
*Saskatoon, Saskatchewan*

Jon Booker
*Texas Tech University*
*Lubbock, Texas*

Zhenyi Du
*University of Minnesota*
*St. Paul, Minnesota*

Kelly Foley
*Oregon State University*
*Corvallis, Oregon*

Nathan Holeman
*University of Arkansas*
*Fayetteville, Arkansas*

William McDougall
*University of Arkansas*
*Fayetteville, Arkansas*

Anh Nguyen
*University of Missouri*
*Columbia, Missouri*

Ryan Van Roekel
*University of Arkansas*
*Fayetteville, Arkansas*

Terea Stetina
*University of Arkansas*
*Fayetteville, Arkansas*

Lauren Vitko
*The Pennsylvania State University*
*State College, Pennsylvania*

Hongshun Yang
*University of Minnesota*
*St. Paul, Minnesota*

We, the *Student Voice* representatives of NABC's 24th annual conference, heartily thank those behind the *Student Voice* program for making our participation possible and welcome. The discussion at this meeting has been provocative and stimulating, and we came away from it with something more to consider which will broaden our research in the area of water sustainability in agriculture.

Many issues in the area of water sustainability could drive discussion for weeks, but throughout the conference, a couple of major themes emerged repeatedly. Below we mention in brief a few of our thoughts on those major themes as well as a few comments on the conference in general in hopes that future meetings can be even more productive.

The major themes are education, communication and collaboration, and policy changes. As technology continues to advance through the efforts of many like those at this meeting, there are issues that arise with a stronger focus on social and economic problems that we, as the upcoming research generation, feel deserve more discussion and action.

[2]Verbal reporter at the conference and author with contributions from the other students.

## Major Themes

### *Education*

- A disconnect exists between the source and the shelf for products in the United States, perpetuating the idea that consumer decisions have little impact on the environment and local and global economies. This can be remedied through consumer education, possibly through:
  - — Branding (*e.g.* animal friendly, rainforest friendly, fair-trade)—a mark for sustainable agricultural practices.
  - — A recognizable symbol (Smoky the Bear for conservation!) that people will associate with good and healthy conservation practices to encourage smart consumer choices.
- Changing societal values and human behavior will come only through education and involvement at a community level.
  - — More involvement with extension and other organizations (*e.g.* SWCD[3]) is important.
- As was mentioned in the conference, changes may only come generationally.
  - — Can we change curricula across the country such that we emphasize the importance of conservation for a new generation?
  - — Even current curricula that stress conservation are behind on current issues; updating is needed without underestimating the intelligence and resilience of children.
- Children are unaware of current science.
  - — They need more encouragement to join STEM[4] (and add water education to current STEM programs).
  - — Start STEM initiatives at an earlier age.
- If children (and adults) had accurate information, they might be more concerned and make better decisions.

### *Communication and Collaboration*

- There seems to be a lack of knowledge/wisdom about connecting the science to the ground level.
- If a lead area farmer learns about new technologies, but doesn't take those back to the farm, it's not going to be implemented.
- There needs to be better communication among all parties involved in producing, supplying, and consuming products.

---

[3]Soil and water conservation districts.

[4]Science, technology, engineering, and mathematics.

- We have blinders on—everyone here is approaching the problem from their perspective, which is fine to a degree, but until we have a more multi- and inter-disciplinary approach as well as better communication along the entire supply chain (farmers, suppliers, consumers, tech, research, policy), things are not going to change very fast.
- Combining disciplines could improve management practices more efficiently.

### *Policy Changes*

- Groundwater is being depleted and other current practices are not sustainable, so the question is how do we change?
- Our system is basically agricultural survival of the fittest without capital.
- Is it possible to incentivize change through policymaking or through changing current subsidy practices?
- Some current policies/regulations are outdated and limiting, sometimes too stifling for efficient operations.
- Regulations that resulted from lawsuits, and were then applied broadly, may not always work well.
- Can we move subsidies to try cost-share programs with smaller-scale farmers in order to encourage application of more efficient technologies?

### *General Comments on NABC 24*

- There was not much give and take.
- We would like to see more representation from all groups involved: farmers, suppliers, policymakers in equal representation with the researchers.
- If we want to encourage grassroots participation, then we'd like to see more representation of grassroots-level groups at this kind of discussion.
- We would also like to see more discussion and research around the human dimensions of applying new biotechnology.
- Finally, we would like to see and hear more about interdisciplinary work and solutions than about problems with only a few varied solutions.

## PART VI — POSTERS[1]



[1]Editors' note: The poster papers and abstracts have been edited only for formatting. Texts have not been altered.

# *Growing Rice With Less Water*

Merle Anders, K.B. Watkins, P. Counce and S. Kerr
*Rice Research and Extension Center*
*University of Arkansas,*
*Stuttgart, Arkansas*

rrec_manders@futura.net

## Abstract

Effective and efficient irrigation practices are critical to successful rice production and to the sustainability of rice production. To better understand how to address the issue of water management in rice we initially installed water flow meters on two studies that were designed to evaluate disease incidence using fertility, variety/hybrid, and water management as treatment variables. One study evaluated six varieties/hybrids over a range of nitrogen levels. We found that increased nitrogen levels resulted in increases in the time varieties/hybrids were flooded and that to best describe this effect we needed to utilize a detailed growth-staging system. A second study evaluated four cultivars/hybrids under water management options of flood, row, row-flood, flood-row and two nitrogen fertility levels. This study showed that water savings were possible and that each variety/hybrid responded differently to all treatments and to describe these differences we needed to intensify our use of growth-staging. In 2011 a study using two hybrids and six water management systems was initiated. Main plot irrigation treatments are: 1) flood, 2) row/40%, 3) row/60%, 4) IWD/40%, IWD/60%, and IWD/40%-flood. Row management consisted of planting rice on beds and irrigating down a furrow between the beds while intermittent wetting and drying (IWD) consists of flooding the field to a 10-cm depth and allowing the water to recede and the field to dry to the designated percentage of field capacity and then flooding the field to a 10-cm depth. This process is repeated throughout the season while the row watered treatment is watered each time the soil dries to the designated percentage of field capacity. Our 2011 data indicated significant water savings were possible using the IWD approach while row watering resulted in lower grain yields.

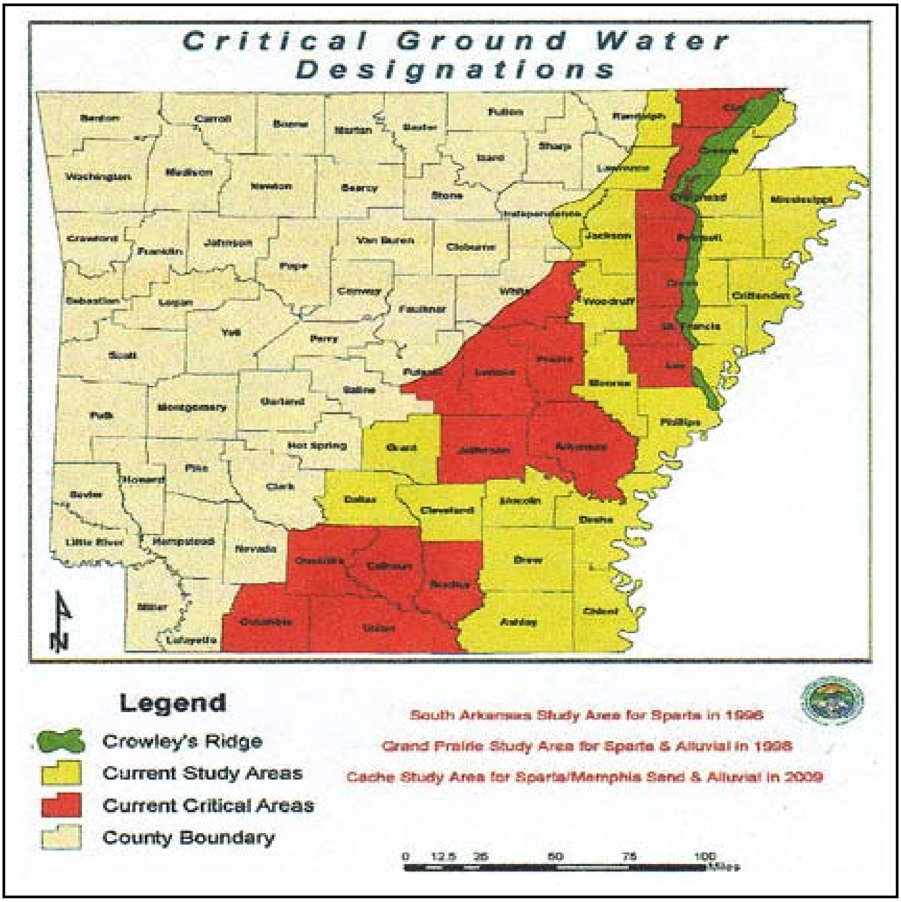



Figure 1. Critical groundwater designations: Arkansas Natural Resource Commission (2011).

## Background

More than 80% of the US rice crop is grown in the Mississippi River Alluvial Plain. In Arkansas, this area covers nearly ⅓ of the eastern portion of the state. In Arkansas ground water provides 63% of the state's total water consumption, and 95% of the ground water use comes from the alluvial aquifer (ANRC, 2012). Agriculture accounts for 96% of the water drawn from the alluvial aquifer with rice production being the most demanding on this resource. In 2011 the Arkansas Natural Resources Commission estimated that only 59.3 and 61.1 percent of the alluvial and Sparta/Memphis aquifer withdrawal, respectively, are currently sustainable. These data support the declaration of critical groundwater zones (Figure 1) and the determination of the percent of sustainable water use in many of the rice production areas of the state (Figure 2). Against this background we began, in 2010, measuring irrigation water use on a series of studies designed to measure disease pressure.

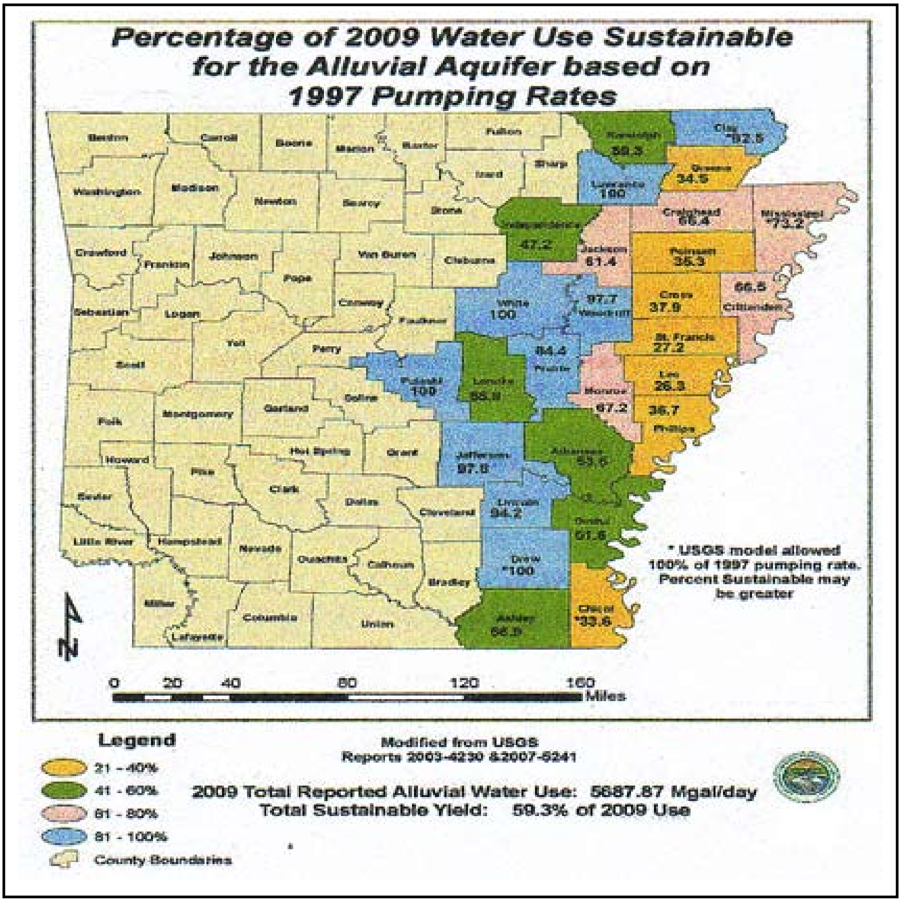



Figure 2. Percentage of water use sustainable for the alluvial aquifer based on 1997 pumping rates. Arkansas Natural Resource Commission (2011).

These studies contained variety × fertility × irrigation treatments. Initially our objective was to evaluate the feasibility of adding a water measure component to existing studies in order to provide us with a background in collecting data from water studies. Currently our studies focus on water management strategies that will allow farmers to economically produce rice while reducing their water use.

## Study Structure

In 2010, flow meters were installed on two studies that were designed to measure the effect of nitrogen (N) fertility rates and irrigation management on false and kernel smut diseases over a range of varieties/hybrids. The first study contained three short-duration and three long-duration varieties/hybrids. The plants were grown using N rates of 112, 157, 202, and 246 kg N $ha^{-1}$. In this study we collected a "standard" data set including date of planting, date of emergence, date of 50% heading, and harvest date. Near the end of the growing season we added the R7 (Counce *et al.*, 2000) (Figure 3) date. In the second study we evaluated four varieties/hybrids under two N fertility levels (112, 202 kg N $ha^{-1}$) and four irrigation management treatments (flood, row, row-flood, flood-row).

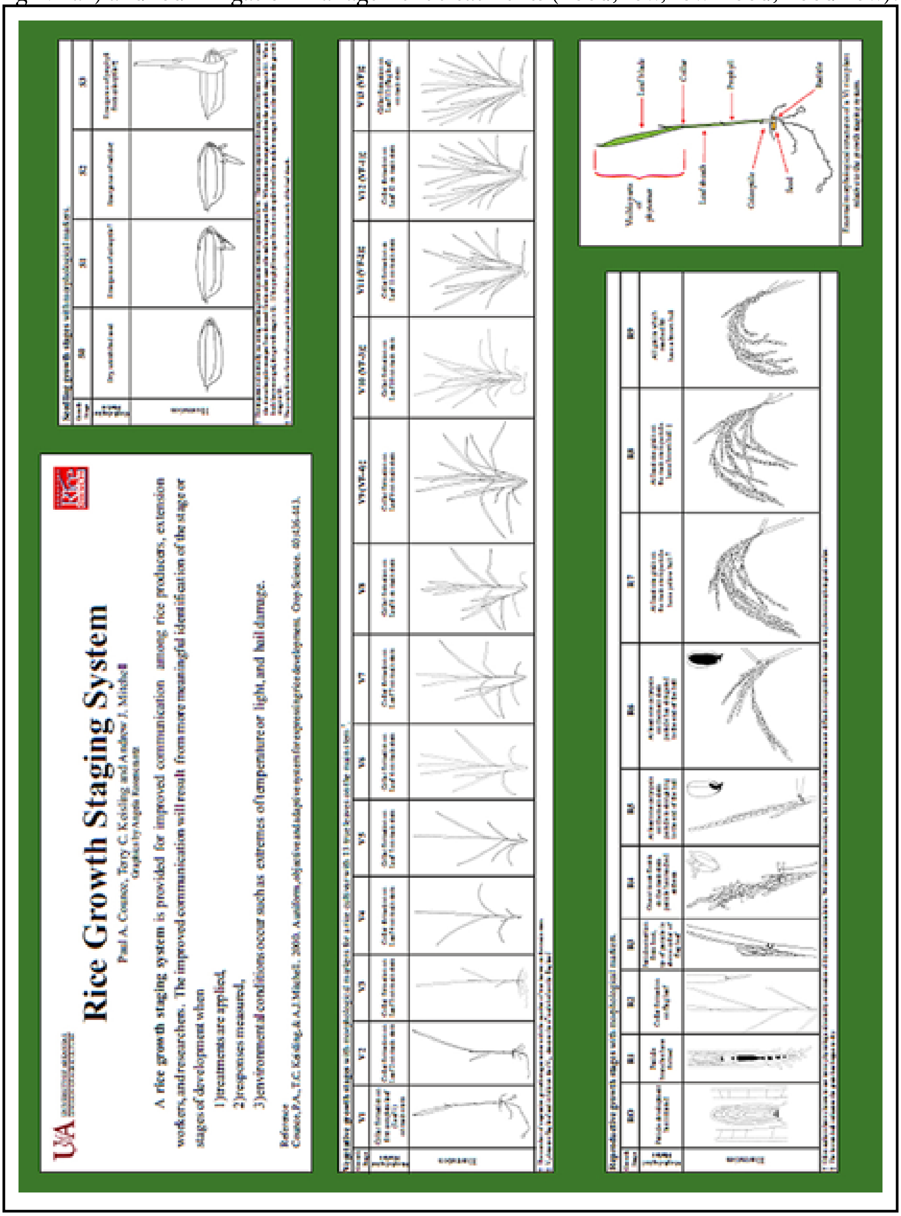



Figure 3. Growth staging system as proposed by Counce *et al.* (2002).

Row-watered consisted of planting the rice on 76-cm beds and running water down the furrow between beds. Where irrigation management changes were made during the growing season these changes were made at "green ring" or when the plant moved from vegetative to reproductive. The same data was collected as in the first study.

## Results

Together these studies provided us with valuable information on the types of plant data we need to accurately report out findings. Our initial data collection included only a predicted date of draining generated using the DD50 program. We found this estimate to not be accurate in that it did not compensate for differences in plant growth attributable to study treatments. We have now adopted the plant growth staging system first reported by Counce *et al.* (2000). Our findings indicate N rate can significantly increase flooding time (flood application to R7) (Figure 4) and the length of time flooding is extended is

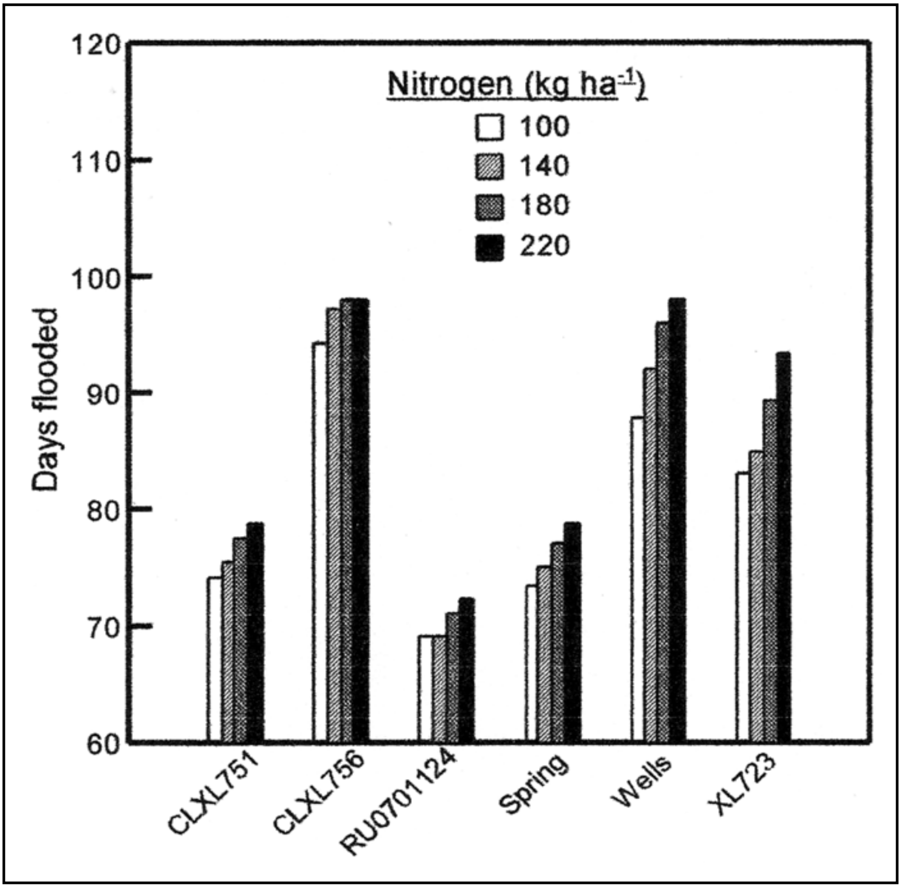



Figure 4. Days flooded (days permanent flood to R7) for six varieties/hybrids grown under for irrigation treatments.

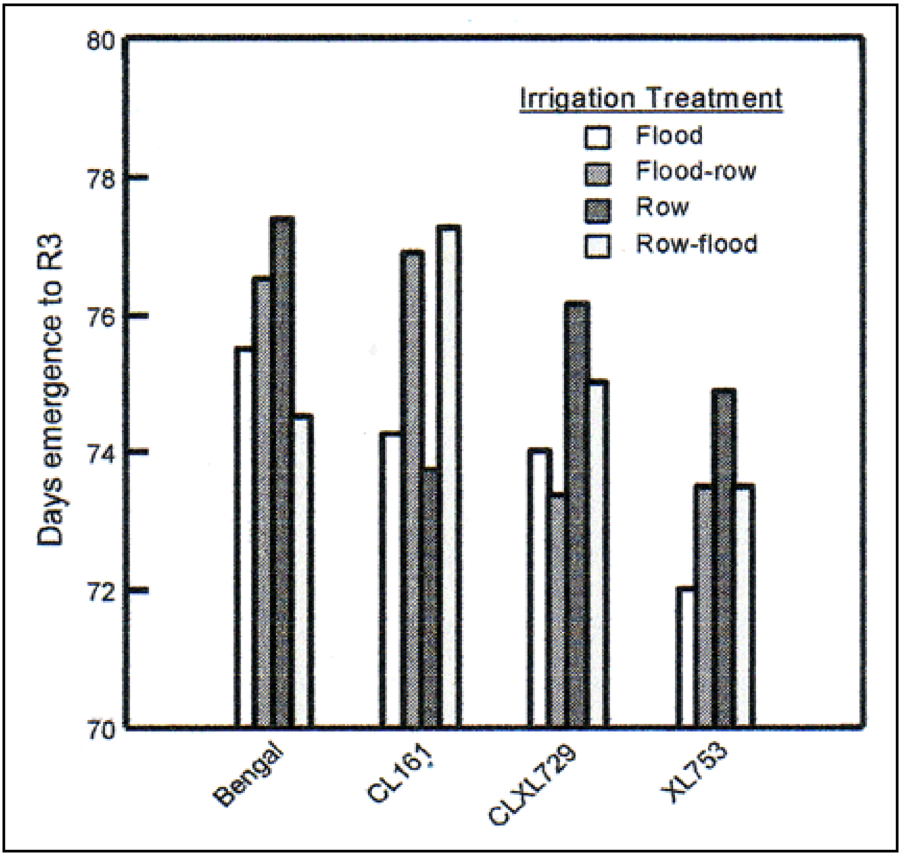



Figure 5. Days from emergence to R3 (50%) heading for four varieties/hybrids grown under flood, row, flood-row, and row-flood irrigation management systems. Row indicates watering was done in furrows between beds and field was aerobic. For treatments where the flood management was changed, this change took place at R0-R1.

dependent on cultivar/hybrid. For all varieties/hybrids tested, increasing N fertility rates extended the flooding time and that, for each variety/hybrid, grain yields did not increase with extended flooding times. Using a "standard" estimate of drain date in relationship to flowering date was not accurate and significant water savings could be realized by no over-fertilizing with N.

In the second study we found that days from emergence to R3 (50% heading) was significantly affected by irrigation treatment and was variety specific (Figure 5). Data on days from emergence to R3 further support the need to combine plant-growth data with plot management as a way to better understand the impact of growing rice with less water. The varieties/hybrids used in this study did not respond similarly to irrigation management systems for days from R3 to R7 (Figure 6). Having an accurate determination of

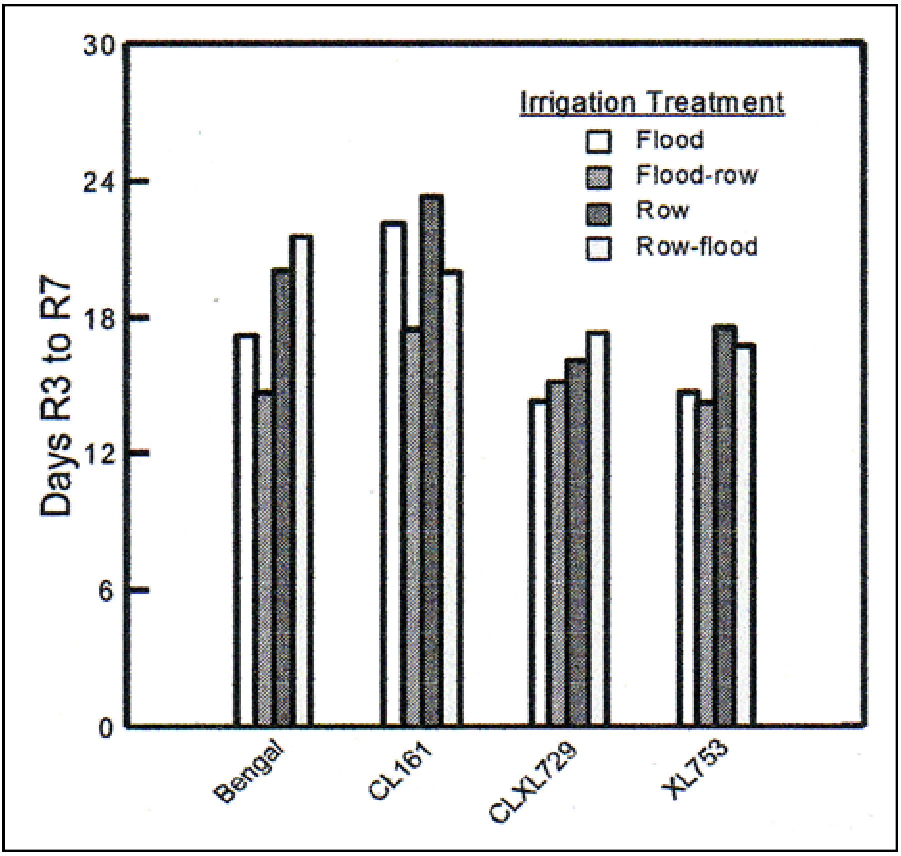



Figure 6. Days from R3 (50%) heading to R7 (water removal) for four varieties/hybrids grown under four irrigation management systems. Row indicates watering was done in furrows between beds and field was aerobic. For treatments where the flood management was changed, this change took place at R0-R1.

this response facilitated the determination of the days in which each variety was flooded or received irrigation water (Figure 7). In general, all varieties/hybrids received water applications for a shorter time when they were either flooded through the entire season or only during the plants vegetative growth stages (flood-row). Data on days receiving water proved useful to determine the effects of irrigation treatments on an individual variety/hybrid but did not answer the question of how much water was used to produce a specified amount of grain. The first step in determining this was to utilize water measurements made on each irrigation management treatment. Because each irrigation plot contained all four varieties we used the "water treatment" average to determine overall water use. In this study total irrigation water applied was: flood = 3,701 $m^3$, row = 2,159 $m^3$, row-flood = 2,262 $m^3$, flood-row = 2159 $m^3$. The row, row-flood, and flood-row

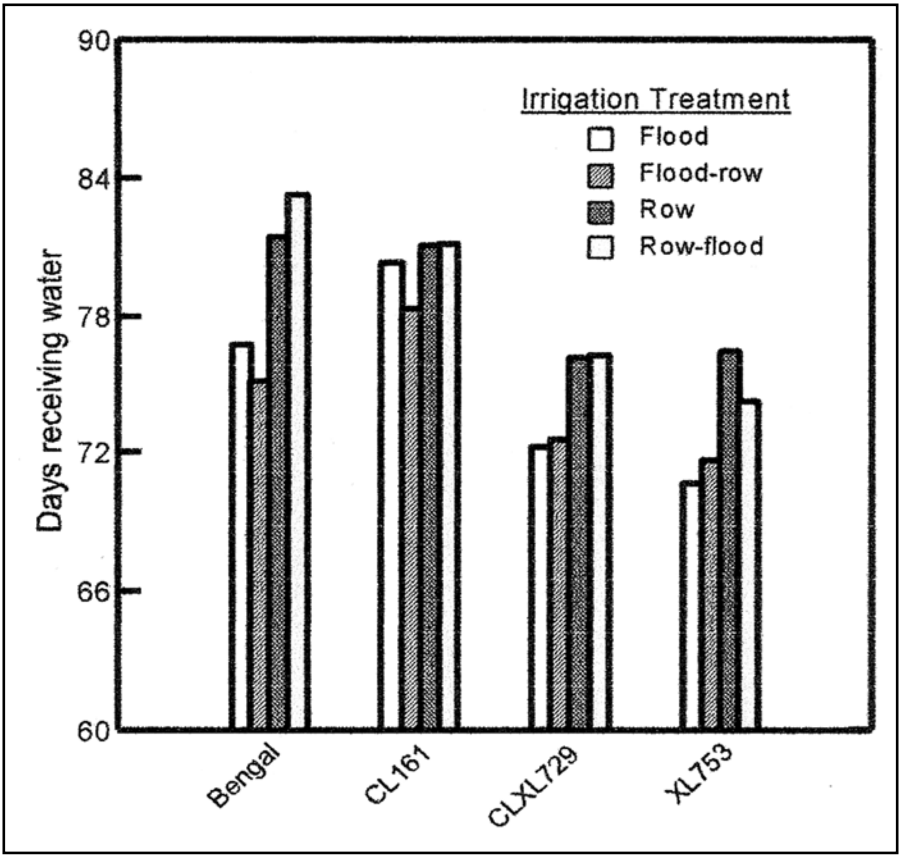



Figure 7. Days each variety/hybrid received water for four irrigation treatments. For flooded treatments this represents the days flooded, for non-flooded treatments this represents the time (days) from the first water application to the day of the last water application. Row indicates watering was done in the furrows between bed and field was aerobic. For treatments where the flood management was changed, this change took place at R0-R1.

irrigation treatments were similar while the flood treatment required significantly more water. To determine water efficiency we chose to "yield scale" our data. Rice grain yield was both cultivar/hybrid and irrigation management strategy dependent (Figure 8). From these data we were able to compare the volume of water ($m^3$) used for each kilogram of rice produced. These data helped us select varieties/hybrids and water management treatments in our current research program.

## Current Study

In 2011 we initiated a irrigation study with the support of the Arkansas Rice Research and Promotion Board that will better evaluate the potential of producing rice with less

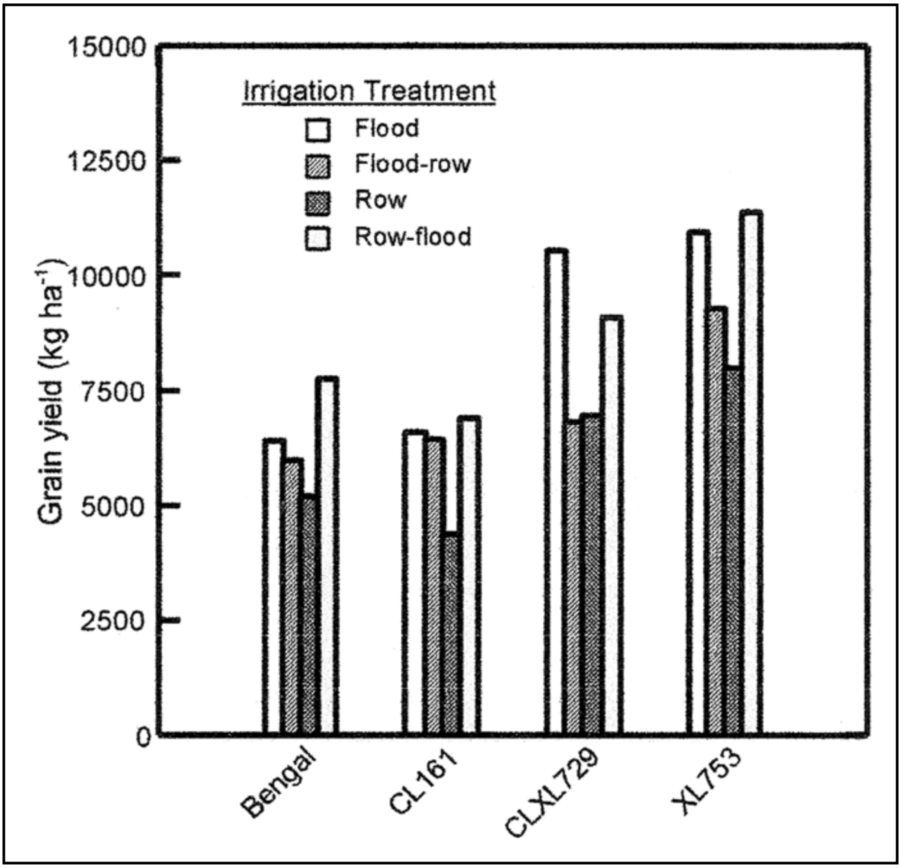



Figure 8. Rice grain yield (kg ha$^{-1}$) for four varieties/hybrids grown under four irrigation management strategies. Row indicates watering done in furrows between beds and field was aerobic. For treatments where the flood management was changed, this chance took place at R0-R1.

water. This study has a single nitrogen rate (134 kg N ha$^{-1}$), two hybrids (CLXL745, XL753), and six water management treatments: 1) flood, 2) row/40%, 3) row/60%, 4) IWD/40%, 5) IWD/60%, and 6) EWD/40%-flood. The percentage value following the irrigation treatment designation represents the percent of field water capacity remaining in the soil when the water is applied. For the intermittent wetting and drying (IWD) treatments the plot is filled to a water depth of 10-cm and not refilled until the water evaporats and the soil reaches the designated soil water percentage for that treatment at which time the plot is pumped to the 10-cm depth. In our earlier work we found that grain yield generally decreased with reduced water treatments. In this study grain yields were significantly affected by irrigation treatments (Table 1). Similarly to our earlier work, grain yeidl in the row watered treatments was significantly lower than other treatments. Using the procedure described earlier we calculated water efficiency for each treatment combination (Table 2). These data show that grain yields were similar to, or greater, in the IWD treatments when compared to the flood treatment while less water was used. This resulted in significant gains in water savings. We have not included rainfall inour calculations as that will vary across years. In this case it was approximately 12-18-cm

*Table 1. Analysis of varience (ANOVA) for grain yeild pooled across two hybrids for the 2011 rice irrigation study. Values followed by different letters are different at the $P<0.05$ level.*

| Irrigation treatment | Grain yield (kg ha$^{-1}$) |
|---|---|
| Flood | 10886A |
| IWD-40%– Flood | 10584A |
| IWD-60% | 10433A |
| IWD-40% | 10130A |
| Row-40% | 7157B |
| Row-60% | 7560B |

*Table 2. Summary of grain yield (kg ha$^{-1}$), water used (m$^3$), and water efficiency (m$^3$ $H_2O$ kg$^{-1}$ grain) for the 2011 reduced water study. Water used does not include rainfall captured throughout the season in the IWD treatments.*

| Treatment | Hybrid | N applied (kg ha$^{-1}$) | Yield (kg ha$^{-1}$) | Efficiency (m$^3$ $H_2O$ kg$^{-1}$ rice) | Water used (m$^3$) |
|---|---|---|---|---|---|
| Flood | CLXL745 | 134 | 10685 | 0.35 | 3701 |
| Flood | XL723 | 134 | 11038 | 0.34 | |
| IWD* - 40 | CLXL745 | 134 | 10332 | 0.13 | 1336 |
| IWD – 40 | XL723 | 134 | 9929 | 0.13 | |
| IWD – 40 - Flood | CLXL745 | 134 | 10433 | 0.20 | 2056 |
| IWD – 40 - Flood | XL723 | 134 | 10735 | 0.19 | |
| IWD – 60 | CLXL745 | 134 | 10534 | 0.16 | 1748 |
| IWD – 60 | XL723 | 134 | 10332 | 0.17 | |
| Row – 40** | CLXL745 | 134 | 7510 | 0.27 | 2056 |
| Row – 40** | XL723 | 134 | 6804 | 0.27 | |
| Row – 60** | CLXL745 | 134 | 7056 | 0.29 | 2056 |
| Row – 60** | XL723 | 134 | 7157 | 0.29 | |

throughout the season . The rainfall occurred at a time all the IWD treatmetns were nearly ready to be flooded thus we captured that water in those treatments. At one point we were able to go 33 days between water applications. This was in one of the hottest, driest, summers in recorded history.

Our results indicate great potential in saving water in rice production. This is not without cost as many farmers would need to invest in land leveling and upgraded water delivery systems to make these water management strategies work. We highly recommend that all research carried out on water management include information on plant growth staging. By doing this results will be easily camparable and recommendations to farmers easier to follow.

## References


Arkansas Natural Resources Commission (2011) Arkansas ground-water protection and management report 2011. Little Rock: Arkansas Natural Resources Commission.

Counce PA *et al.* (2000) A uniform and objective and adaptive system for expressing rice development. Crop Science 40 436–443.

# *Developing a Web-Based Forecasting Tool For Nutrient Management*

P.J. Drohan[1], A.R. Buda[2], P.J. Kleinman[2], D.A. Miller[1], P.G. Knight[1], D.B. Beegle[1] and H. Lin[1]

[1] *The Pennyslvania State University University Park, Pennsylvania*

[2] *USDA-ARS Pasture Laboratory University Park, Pennsylvania*

pjd7@psu.edu

US and state nutrient management planning provides strategic guidance that, in the best cases, educates farmers and others involved in nutrient management to make prudent management decisions. The strategic guidance provided by nutrient management plans does not provide the day-to-day support required to make operational decisions, particularly when and where to apply nutrients over the short term. These short-term decisions on when and where to apply nutrients can make the difference between whether the nutrients impact water quality or are efficiently utilized by crops. Infiltrating rainfall events occurring on the heels of broadcast nutrient application are beneficial, as they will wash soluble nutrients into the soil where they are used by crops. Rainfall events that generate runoff (Figure 1) shortly after nutrients are broadcast will wash off applied nutrients, producing the largest losses of nutrients possible from that site.

Our goal is to develop a research driven support tool for nutrient management, the Fertilizer Forecaster (Figure 2), which identifies the relative probability of runoff or infiltrating events in Pennsylvania (PA) landscapes. This tool will support field specific decisions by farmers on when and where to apply fertilizers and manures over 24, 48 and

Figure 1. Example of rainfall generated surface runoff.

72 hour periods. Our objectives are to: (1) monitor agricultural hillslopes in watersheds representing four of the five Physiographic Provinces of the Chesapeake Bay basin (*Appalachian Piedmont (Conewago Creek watershed, PA), Appalachian Valley and Ridge Province – acid shale and sandstone (Mahantango Creek watershed, PA), Appalachian Valley and Ridge Province - karst (Spring Creek watershed, PA), Allegheny Plateau Province (Anderson Creek watershed, PA))*(Figure 3); (2) validate a high resolution mapping model that identifies soils prone to runoff; (3) develop an empirically based approach to relate state-of-the-art weather forecast variables to site-specific rainfall infiltration or runoff occurrence; (4) test the empirical forecasting model against alternative approaches to forecasting runoff occurrence; and (5) recruit farmers from the four watersheds to use web-based forecast maps in daily manure and fertilizer application decisions.


Figure 2. The Fertilizer Forecaster WWW interface.

Within each watershed, we will select two farms and apply a pedogenic model to differentiate soils prone to saturation or infiltration excess runoff. Participating farmers, members of the PA Conservation Commission, and PA NRCS will form a project advisory committee providing input into forecasting model selection and web-tool development. We will monitor soils prone to saturation and infiltration excess runoff, obtaining measurements of site meteorology, soil moisture, shallow groundwater depth, surface runoff occurrence and surface runoff volume. Monitoring results will be used to generate site-specific algorithms of runoff occurrence and compared with alternative forecasting models to assess the advantages of region-specific vs. generalized approaches. We will assess three modeling approaches (Figure 4) for their potential to forecast surface runoff occurrence and serve as the basis for the web-based "Fertilizer Forecaster" tool: (1) *runoff occurrence algorithms* developed from hillslope monitoring; (2) *saturation zone prediction models* using a topographic index and daily water balance simulations; (3) *NOAA River Forecast Center models* that simulate daily runoff for large watersheds. Each model will be evaluated using standard skill measures that are used by the National Weather Service to verify rainfall occurrence forecasts.

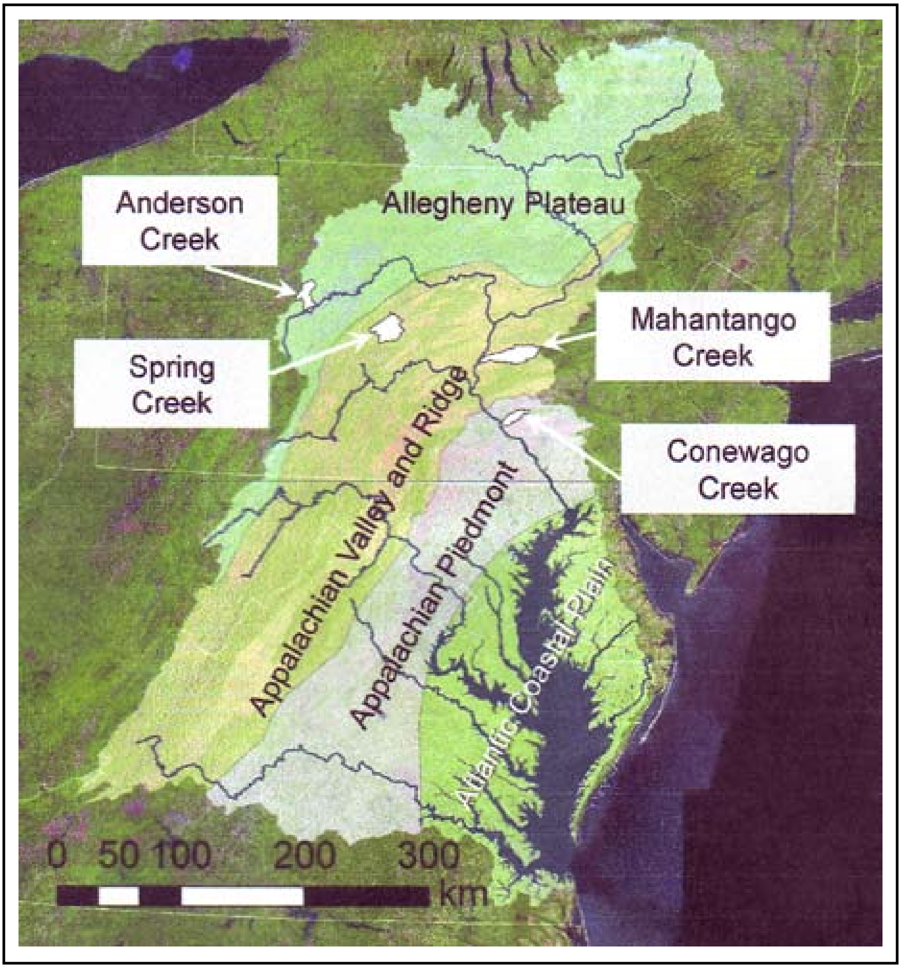



Figure 3. Study watershed locations.

Forecasts of runoff occurrence by each of the models will be recorded and compared to observed data to evaluate the skill of 24, 48, and 72 hr forecasts using standard skill measures employed by the National Weather Service. We will build a prototype of the Fertilizer Forecaster using open source code that is freely available to the public. The prototype will use an Adobe Flash-based interface. We will develop the prototype version of the web-based tool for each runoff prediction model, and train participating farmers (the advisory panel) to use the tool as part of their daily nutrient management decision making. In order to assess the utility of the Fertilizer Forecaster in changing nutrient management decisions, we will ask participating farmers to initiate a log of daily nutrient management and tillage decisions for each field on their farm beginning at the start of the project. This dataset will be used to assess their fertilizer, manure, and tillage management decisions

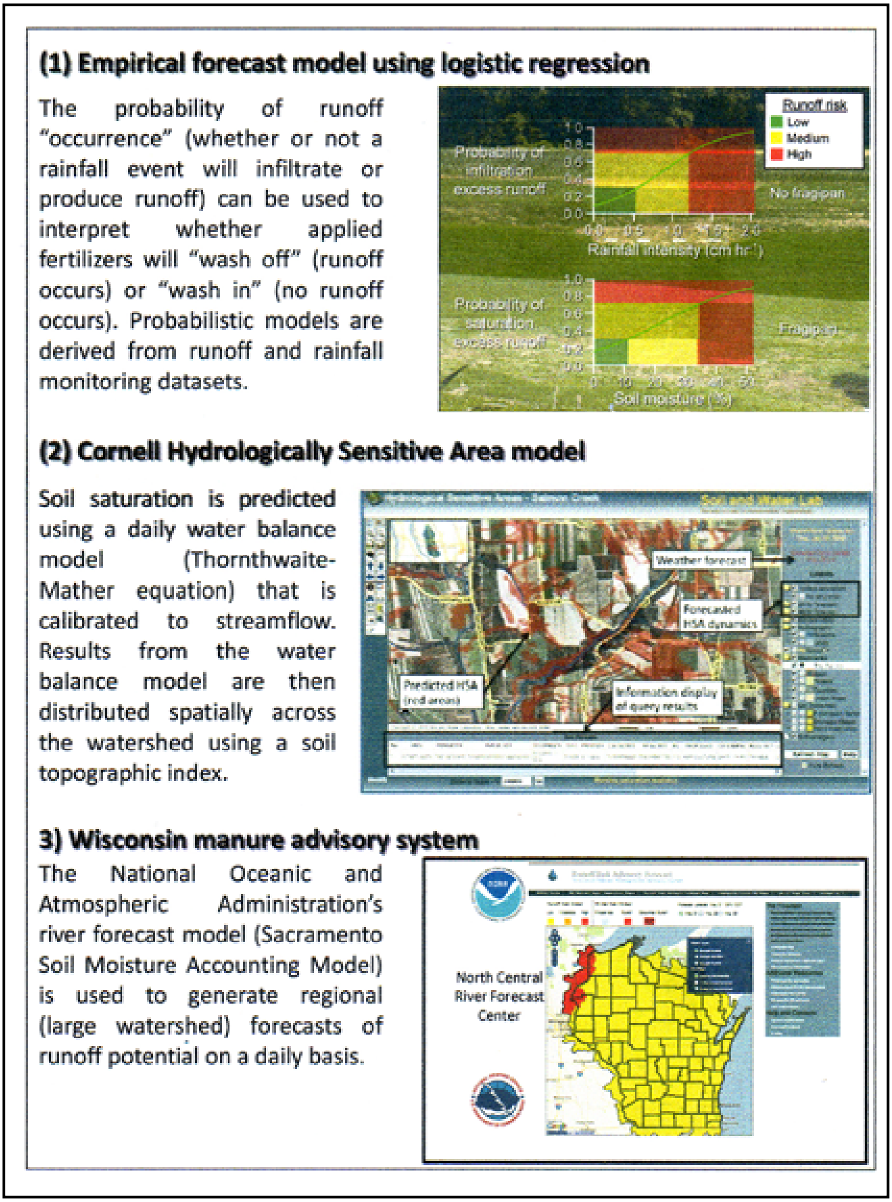


Figure 4. Three modeling approaches to be tested.

before and after use of the tool. Feedback from the farmers and the project advisory panel will be used to revise the tool and select the most suitable model. The final version of the web-based tool will be delivered to the PA Conservation Commission website.

We hope that the Fertilizer Forecaster will serve as the basis for state (PA), regional (Chesapeake Bay), and national changes in nutrient management planning. Site development and field monitoring will begin in 2012 and continue into 2015. Model and tool development will begin in 2012 and have an operating prototype available by 2014. The model and tool will be refined through 2016. An outside advisory panel consisting of farm professionals will be formed in 2012, and used throughout the project to advise on tool usage and improvement. Beginning in year 3 of the study, a beta version of the Fertilizer Forecaster will be provided to participating farmers, all of whom will be expected to use it on daily basis during periods of fertilizer and manure application. These members will also help to communicate the tools effectiveness. Following extensive model testing and review, a final model will be chosen and the Fertilizer Forecaster tool will be delivered to the PA Conservation Commission and published on their website (2016). The tool will be operational in all four watersheds where it was tested and developed; however, we will begin to educate users outside the region on the application of the tool and its potential usefulness in managing nutrient application. This will occur via a variety of regional outreach events that the grant team currently participates in. In addition, post-grant activity will involve obtaining additional funds to expand the Fertilizer Forecaster tool to the entire state.

# *Mass Cultivation of Mixotrophic Algae for Biofuels Production and Wastewater Treatment*

Zhenyi Du, Liang Wang, Wenguang Zhou and Roger Ruan
*University of Minnesota*
*Saint Paul, Minnesota*

duxxx115@umn.edu

## Abstract

Proposed microalgae bioenergy crop production systems utilizing organic-rich agricultural waste streams have gained increased attention recently for their increased economic and environmental benefits. Seventeen mixotrophic locally isolated strains, which adapted well in organic carbon-rich concentrated municipal wastewater and agricultural wastewater, have been identified by multi-step screening and acclimating procedures. These strains were identified as *Chlorella* sp., *Heynigia* sp., *Hindakia* sp., *Micractinium* sp., and *Scenedesmus* sp.. They were chosen for further studies because of their high growth rates of 0.292 - 0.498 $d^{-1}$ and high lipid productivity of 50-77.8 mg $L^{-1}d^{-1}$. A novel two-stage hetero- and photoautotrophic algae culture process for improved wastewater nutrient removal and algal biomass production was investigated. The nutrient removal efficiencies for Ammonia, Total nitrogen, Total phosphors and Total organic carbon were 100%, 85.7-92.5%, 96-97.4%, and 47.5-81.4%, respectively. A low-capital cost, low maintenance cost and highly scalable hybrid cultivation system for year-round production of algae in northern climate has been developed. Harvested algal biomass were directly converted into biofuels by microwave-assisted pyrolysis and hydrothermal liquefaction processes. Characterization of the produced bio-oil showed that it has very similar compositions to fossil oils. The aqueous phase products, which contain significant amount of nutrients, can be recycled to the wastewater stream for algae cultivation. Based on the results, an integrated biorefining system has been proposed which includes algal biomass production on wastewater, processing of algal biomass to biofuels, and water and nutrients recycling for algae cultivation, and therefore this biorefining system has a great potential to play a dual role of wastewater treatment and biofuel production.

# *Possible Benefits of Introducing Strip Tillage to Improve Farming Practices and Water Quality*

Kelly M. Foley[1], Clinton C. Schock[1] and O. Stephen Norberg[2]

[1]*Oregon State University*
*Corvallis, Oregon*

[2]*Washington State University*
*Pullman, Washington*

foleyke@science.oregonstate.edu

## Abstract

Agricultural practices are needed that will increase production efficiency and reduce the offsite effects of production, especially for irrigated agriculture in the Pacific Northwest. Strip tillage is a form of conservation tillage where crop residue is retained on the soil surface. Under strip tillage the soil is not plowed and only a narrow band of soil is tilled directly in line with the planting of seed. Strip tillage offers possible environmental and economic advantages to growers who convert from conventional tillage. The purpose of this study was to determine whether strip tillage would yield the same economic and environmental advantages in Malheur County, Oregon as found by growers in other parts of the country. Four producers' fields were used to make side by side comparisons of conventional and strip tillage methods. Soil residue cover, soil moisture, and crop yield were measured. Soil tillage intensity (STIR), ratings of soil conditioning index (SCI), soil erosion, and fuel usage were estimated based on actual field operations. Strip tillage retained more crop residues on the soil surface, reduced disruption of the soil, had less risk of soil erosion than conventional tillage (STIR). The SCI ratings estimated better soil structure following strip tillage than conventional tillage in all four fields, with actual gains in soil organic matter predicted for three of the four fields. All four fields were over-irrigated during most or all of the growing season, so benefits of strip tillage in retaining soil moisture could not be measured. Crop yields were equivalent between the tillage systems and fuel costs were reduced by strip tillage. These findings are being shared with the local community at a variety of meetings, field days, reports, and grower's guides with the goal of encouraging the adoption of conservation tillage in the Pacific Northwest.

# *Bioremediation of Swine Wastewater Using Attached Algae Production*

N. Holeman, J.D. Jackson, M.D. Matlock and T.A.Costello
*University of Arkansas*
*Fayetteville, Arkansas*

nholeman@yahoo.com

## Abstract

Water bodies in northwest Arkansas are enriched with nitrogen and phosphorus due to land use activities in urban and agricultural areas near the Beaver Lake Basin. Despite this problem, current agricultural waste management practices can be adapted using best management practices to become more environmentally sustainable. The use of attached algae production to treat swine wastewater shows promise as a method to naturally utilize excess nitrogen and phosphorus to produce a renewable bioenergy feedstock. With the removal of nitrogen and phosphorus due to algal uptake, local agricultural waste holding ponds and other water bodies can be managed with less environmental impact. To test practical large scale implementation of this methodology, a wastewater treatment facility that uses attached algae production is being constructed at the University of Arkansas Swine Finisher Unit, near Savoy, Arkansas. The system consists of a 200ft by 25ft flow-way, with a series of tipping buckets to provide surging, multiple pumps to aid in water circulation flexibility, and a mechanized algae harvest sub-system. The system has four parallel flow paths (for testing multiple wastewater sources simultaneously) along a precision grade of 2%. Algae will grow and attach to commercial indoor-outdoor carpet used as growing medium. Algae grown in this facility will be characterized and processed for use as a biofuel feedstock. Such bioenergy production would lower the carbon footprint of the agricultural production system and potentially increase net profit. This research will provide data on productivity and costs so that a life cycle assessment of the system sustainability, from environmental and economic viewpoints, can be performed.

# *A Metabolic Profiling Technique to Assess the Regulation of Stress-Protectant Compounds in* Fusarium verticillioides

Jonathon E. Smith and Burt H. Bluhm
*University of Arkansas*
*Fayetteville, Arkansas*

jes002@uark.edu

## Abstract

*Fusarium verticillioides* is a fungal pathogen that causes Fusarium ear rot of maize. In addition to reducing yield, this fungus can reduce grain quality both by colonizing the kernel and by producing fumonisin mycotoxins. Fusarium ear rot and fumonisin biosynthesis are associated with drought stress and low-moisture kernel environments. In fungi, tolerance to drought and osmotic stress is often attributed to the accumulation of polyols and trehalose which act as osmoregulators. The over-arching goal of this study was to assess environmental and genetic regulation of trehalose and polyol biosynthesis in *F. verticillioides*. To this end, we developed a metabolic profiling technique, which allows simultaneous detection and quantification of multiple carbohydrates. To generate metabolic profiles of *F. verticillioides*, a gas chromatography-mass spectrometry (GC-MS) based technique was optimized to detect 46 metabolites in the wild-type strain. Approximately one third of the fungal metabolites were then identified based on similarity to spectra in commercial databases or retention times of pure standards. Metabolic profiles were then generated for genetically defined mutants and compared to the profile of the wild type. The technique developed in this research was applied to compare metabolic profiles of the wild type and a mutant (Δ*pac1*) containing a disruption in the *PAC1* gene. *PAC1* is a homolog of PacC, a transcriptional regulator of pH dependant metabolic pathways. Significant differences in the accumulation of trehalose and polyols associated with tolerance to drought stress were reliably detected between strains. Additionally, changes in the metabolome of both strains in response to pH were consistently detected. The metabolic fingerprinting technique developed in this study provides a robust tool for the analysis of metabolites associated with tolerance to drought and osmotic stress. In addition, this study has revealed a novel link between *PAC1* and polyol biosynthesis.

# *Geophysical Based Site-Specific Mapping of Fragic Properties to Constrain Hillslope Hydrologic Controls on Variable Source Area Hydrology*[1]

Lauren F. Vitko[1], Patrick J. Drohan[1], Anthony R. Buda[2], Peter J.A. Kleinman[2], and Mary Kay Lupton[1,2]

[1] *The Pennsylvania State University*
*University Park, Pennsylvania*

[2] *USDA-ARS*
*University Park, Pennsylvania*

lfv104@psu.edu

## Introduction

Reduction of agricultural runoff in the Susquehanna watershed is paramount because it contributes waters to the much polluted Chesapeake Bay. In Pennsylvania, approximately a third of the soils are underlain by dense subsoil layers called fragipans (also referred to as fragic properties for more weakly expressed layers) that restrict the movement of water and generate substantially more runoff than soils not containing fragipans.

The USDA Soil Survey provides information on the presence of a fragipan (and drainage class), but it is not detailed enough to delineate regions prone to saturation at the field-scale. Imaging of the subsurface using ground penetrating radar (GPR), in conjunction with soil augering, provides an efficient method for high-resolution soil mapping; however, prior research utilizing GPR for fragipan identification is minimal. Information on fragipan extent and depth are much needed for management of nutrient applications on agricultural lands.

[1]See note on figure color on page VIII.

Photograph 1. GPR instrument used.

## Objectives

1. Identify fragipans from GPR radar profiles
2. Interpolate the extent and depth of fragipans in the watershed
3. Compare fragipan model derived from GPR images to soil survey map

## Materials and Methods

### *Field Site*

- The FD-36 watershed is located in east-central Pennsylvania, within the Susquehanna watershed and measures 39.5 ha (Figures 1 and 2)
- Land-use in FD-36 is 50% agriculture, 20% pasture, and 30% woodland

### *GPR System*

- The GPR system used was a SIR-3000 (Subsurface Interface Radar) made by GSSI (Geophysical Survey Systems, Inc.) with a 400 MHz antenna

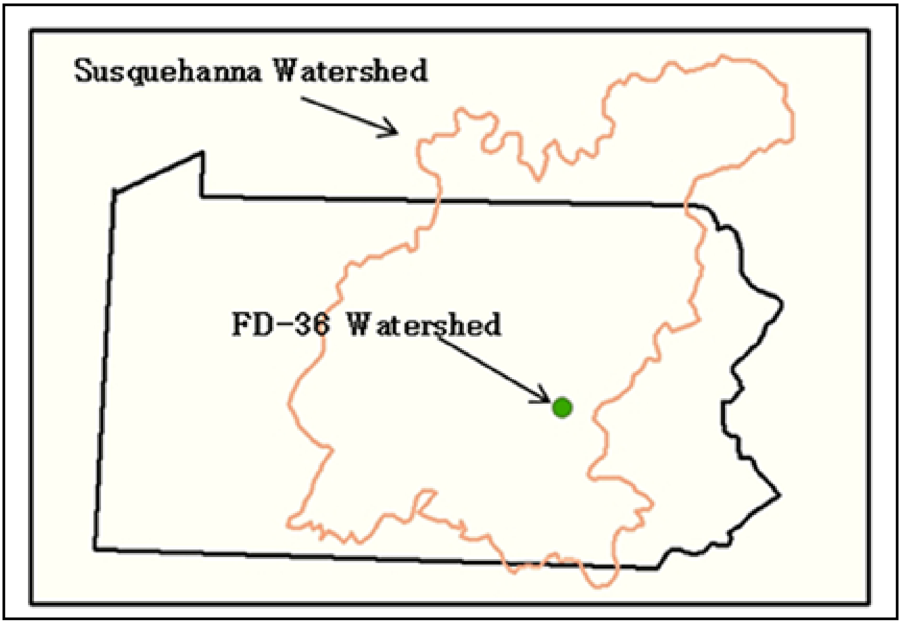



Figure 1. Location of FD-36 watershed in Pennsylvania. Modified from Needleman (2002).


Figure 2. FD-watershed showing the watershed boundary (outer white polygon), GPR transects (white lines), region of watershed where interpolation was performed (black square), and reference soil pits (stars).

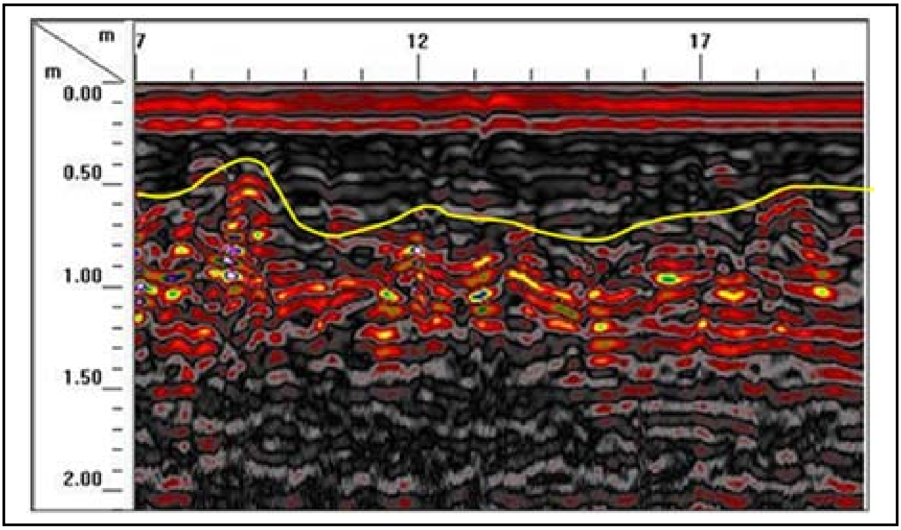



Figure 3. Radar profile taken adjacent to reference soil pit known to contain a fragipan (located at south footslope; see Figure 2). Fragipan begins at approximately 50–100 cm (yellow line).

- A Trimble GeoExplorer 2008 Series GPS (connected to a Acumen GPS data logger) recorded geographic coordinates every one second

### *Data Collection*

- 40 GPR transects (5-30 m apart) were run in the north-central portion of the watershed (Figure 2)
- Short GPR transects were also run adjacent to four previously excavated soil pits where soil horizons and properties were described (Lindeburg, 2011) to use as a reference (Figure 2; Figure 3)
- Depth was calibrated by burying a metal object at 25 cm and determining the propagation velocity (0.0948 m/ns)

### *Data Analysis and Interpretation*

- Radar scans were processed with RADAN 7 software
- Inverse distance weighted interpolation of fragipan depth was performed in ArcGIS 9.3.1

## Results and Conclusions

- On the south slope of the watershed, fragipan identification via GPR was similar to fragipan extent mapped in the soil survey
- On the north slope of the watershed, fragipan identification via GPR over-predicted fragipan extent relative to the soil survey

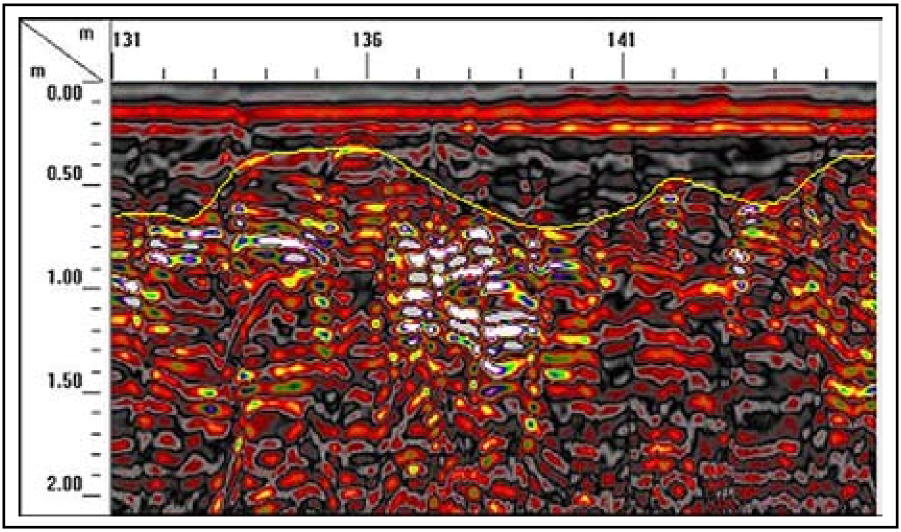



Figure 4a. (legend on p. 268).

- It is presumed that bedrock was interpreted as a fragipan; the reason for this may have to do with the high soil moisture status during data collection
- Because gradations of fragipan expression exist, a precise cutoff between fragipan and non-fragipan status was sometimes difficult
- The usefulness of GPR for identifying fragipans appears to be site-specific and dependent on soil moisture conditions
- Deep soils, without bedrock near the surface, lessens the possibility of mis-identifying bedrock as a fragipan
- Soil moisture status (particularly a perched water table) impacts fragipan appearance on a radar profile

## Future work

- Identify GPR fragipan signature under varying moisture conditions
- Extend fragipan mapping via GPR to other watersheds and regions of Pennsylvania

## References

Lindeburg KS (2011) Silty mantles and fragipans in Pennsylvania soils. M.S. thesis. The Pennsylvania State University, University Park.

Needleman BA (2002) Surface runoff hydrology and phosphorus transport along two agricultural hillslopes with contrasting soils. Ph.D. thesis. The Pennsylvania State University, University Park.

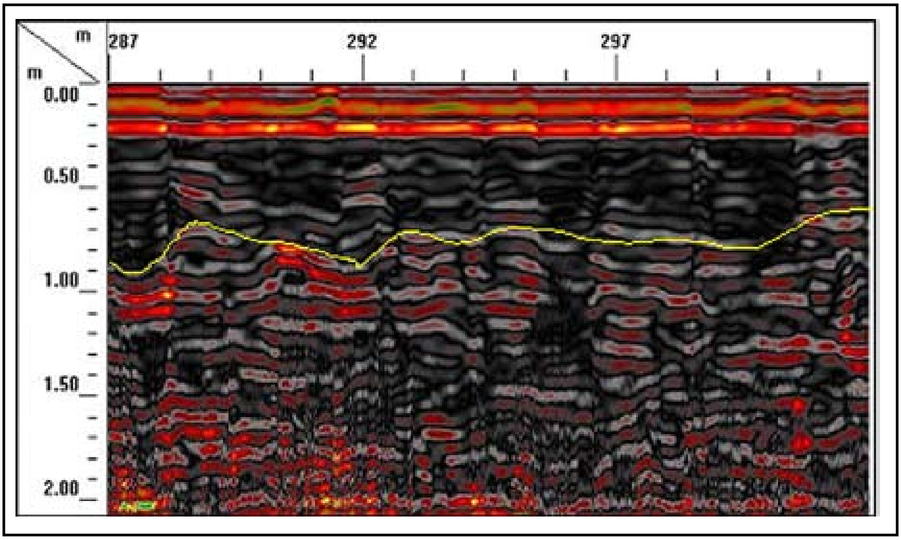
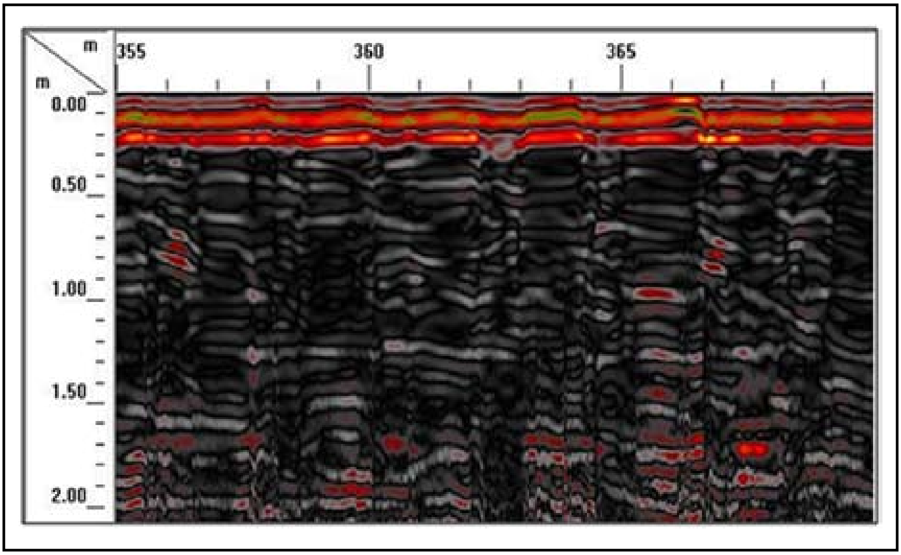



Figure 4b. (legend below).




Figures 4a–4c. Variation in fragipan expression (and/or perched water) along a single transect on the south slope moving uphill a.) Near stream b.) middle slope c.) No fragipan. Yellow line indicates upper boundary of fragipan.

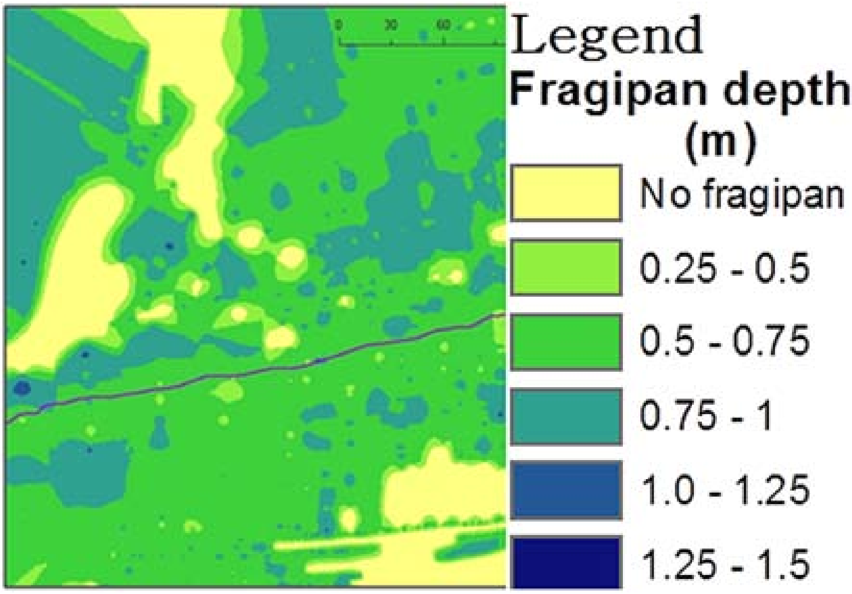



Figure 5. Interpolation of fragipan extent and depth in 12-ha region of FD-36 where data were collected. Stream shown in purple.

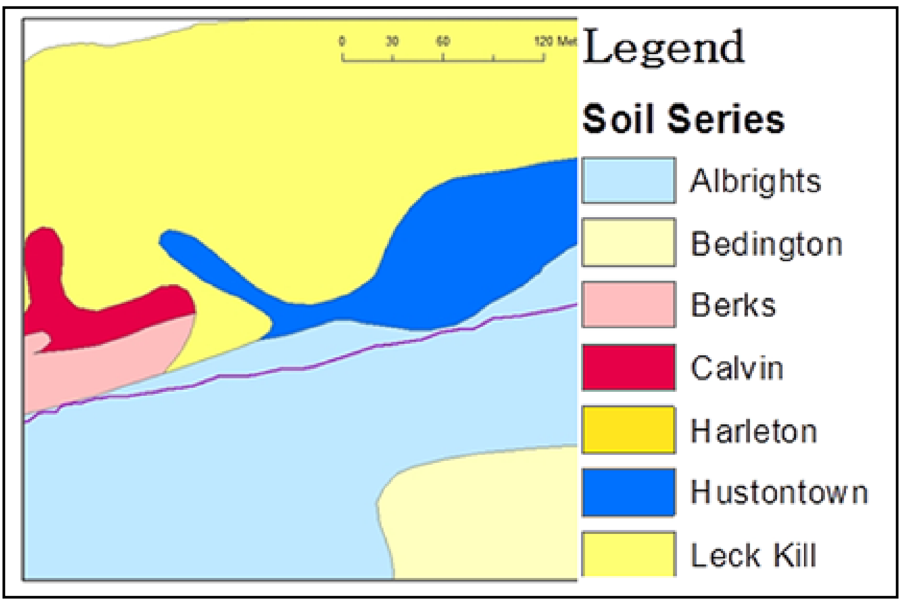



Figure 6. Order 1 soil survey map of the region interpolated for fragipan extent and depth in Figure 5 above. Soils in blue contain a fragipan; yellow and red soils do not contain a fragipan. Stream shown in purple. Modified from Needleman (2002).

# *Sustainable 'Water' Sanitizer: Evaluating Sanitizing Effects of Neutral Electrochemically Activated Water on Foodborne Pathogens*

Hongshun Yang, Joellen Feirtag and Francisco Diez-Gonzalez
*University of Minnesota*
*St Paul, Minnesota*

yang1262@umn.edu

## Abstract

Sanitizing is a key step in ensuring food safety. Neutral electrochemically activated water (NECAW), a sustainable technology, not only has antimicrobial effects but also is relatively friendly to handlers and foods. However, its antimicrobial effects on different pathogens and strains have not been examined. The long-term goal of this project is to investigate the use of NECAW as a sustainable 'water' sanitizer in inactivating foodborne pathogens. The effectiveness and broad-spectrum activity of NECAW against foodborne pathogens were investigated by examining its sanitizing efficacy against 40 different strains of *Escherichia coli* O157:H7, *Listeria monocytogenes*, and *Salmonella* as liquid cultures, dried cells on stainless steel surfaces, and biofilms on stainless steel (SS). It was found that NECAW with 100 mg/L free available chlorine resulted in greater than 5 log CFU/mL reductions for all of the strains in liquid culture, more than 3 log CFU/coupon reductions for 92.5% of the strains dried on SS surface and 27.5% of biofilms. Among all the strains, *S.* Newport B4442CDC was the most resistant strain to NECAW on surfaces while *E. coli* O157:H7 ATCC 43895 was the most resistant strain in biofilms and liquid pure cultures. In contrast, the other commercial technologies tested did not have sanitizing effects. They, however, washed the bacteria on the surface into rinse water, which would be a significant safety concern of cross contamination. Images of biofilm surfaces by atomic force microscopy showed tree-like structures as well as individual microbial cells. *L. monocytogenes* biofilms had a higher percentage of tree-like structures than *E. coli* O157:H7 and *Salmonella*. The tree-like structures and microbial cells on SS were destroyed when treated with NECAW, further supporting that NECAW was effective in controlling surface contamination of pathogenic bacteria and biofilm growth. Overall, NEACW was effective and had a broad-spectrum activity against foodborne pathogens.

# PART VII — PARTICIPANTS

Randy Allen
Oklahoma State University
Ardmore, OK

Marc Andreini
University of Nebraska
Lincoln, NE

Melissa Arkland
University of Saskatchewan
Saskatoon, SK

David Benfield
The Ohio State University
Wooster, OH

Rick Bennett
University of Arkansas
Fayetteville, AR

Burt Bluhm
University of Arkansas
Fayetteville, AR

Jon Booker
Texas Tech University
Lubbock, TX

Bill Branch
Louisiana State University
Baton Rouge, LA

Shane Burgess
University of Arizona
Tucson, AZ

Jamie Burr
Tyson Foods, Inc.
Springdale, AR

Rusty Carter
Texas A&M University
College Station, TX

Douglas Cattani
University of Manitoba
Winnipeg, MB

Kimberly Cochran
University of Arkansas
Fayetteville, AR

Mark Cochran
University of Arkansas
Little Rock, AR

Jed Colquhoun
University of Wisconsin
Madison, WI

Jim Correll
University of Arkansas
Fayetteville, AR

Becky Cross
USDA National Agricultural Statistics Service
Little Rock, AR

Walt Delp
USDA National Resources Conservation Service
Little Rock, AR

Patrick Drohan
The Pennsylvania State University
University Park, PA

Zhenyi Du
University of Minnesota
St. Paul, MN

Allan Eaglesham
National Agricultural Biotechnology Council
Ithaca, NY
607-257-1212
aeaglesh@twcny.rr.com

Margaret Einarson-Smith
Cornell University
Ithaca, NY

Kelly Foley
Oregon State University
Corvallis, OR

Cathy Franck
University of Arkansas
Fayetteville, AR

Kristen Gibson
University of Arkansas
Fayetteville, AR

Ernest Girouard, Jr.
Louisiana State University
Rayne, LA

John Guerber
University of Arkansas
Fayetteville, AR

Ralph Hardy
National Agricultural Biotechnology Council
Ithaca, NY
607-254-4856
nabc@cornell.edu

Chris Henry
University of Arkansas
Stuttgart, AR

Nathan Holeman
University of Arkansas
Fayetteville, AR

Joan Jackson
Salina, KS

Wes Jackson
The Land Institute
Salina, KS

Helen Jarvie
Centre for Ecology & Hydrology
Wallingford, Oxfordshire

Kim Keeney
University of Arkansas
Fayetteville, AR

Shelly Kerr
University of Arkansas
Stuttgart, AR

Jozef Kokini
University of Illinois
Urbana, IL

Ken Korth
University of Arkansas
Fayetteville, AR

Sarah Lewis
University of Arkansas
Fayetteville, AR

Susanne Lipari
National Agricultural Biotechnology Council
Ithaca, NY
607-254-4856
nabc@cornell.edu

Joseph Massey
Mississippi State University
Mississippi State, MS

Marty Matlock
University of Arkansas
Fayetteville, AR

Anna McClung
USDA Agricultural Research Service
Stuttgart, AR

Bill McCutchen
Texas A&M University
College Station, TX

William McDougall
University of Arkansas,
Fayetteville, AR

Richard Moore
The Ohio State University
Wooster, OH

Ruben Morawicki
University of Arkansas
Fayetteville, AR

Cindy Morley
University of Arkansas
Fayetteville, AR

Lacey Nelson
University of Arkansas
Fayetteville, AR

Anh Nguyen
University of Missouri
Columbia, MO

Deanna Osmond
North Carolina State University
Raleigh, NC

Andy Pereira
University of Arkansas
Fayetteville, AR

Abel Ponce de León
University of Minnesota
St. Paul, MN

Jennie Popp
University of Arkansas
Fayetteville, AR

Steven Pueppke
Michigan State University
East Lansing, MI

Thomas Redick
GEEClaw
Clayton, MO

Grace Richardson
University of Arkansas
Fayetteville, AR

Tom Riley, Jr.
University of Arkansas
Little Rock, AR

Samantha Roberson
University of Arkansas
Fayetteville, AR

Lona Robertson
University of Arkansas
Fayetteville, AR

John Rupe
University of Arkansas
Fayetteville, AR

Graham Scoles
University of Saskatchewan
Saskatoon, SK

Danesha Seth Carley
North Carolina State University
Raleigh, NC

Andrew Sharpley
University of Arkansas
Fayetteville, AR

Greg Simpson
RiceTec
Harrisburg, AR

Steven Slack
The Ohio State University
Wooster, OH

Jackie Slovacek
Texas A&M University
College Station, TX

Jonathon Smith
University of Arkansas
Fayetteville, AR

Terea Stetina
University of Arkansas,
Fayetteville, AR

Brenda Stone
Texas A&M University
College Station, TX

Michael Sullivan
USDA Natural Resources Conservation Service
Little Rock, AR

Evan Teague
Arkansas Farm Bureau Federation
Little Rock. AR

Gary Thompson
The Pennsylvania State University
University Park, PA

Keiddy Urrea
University of Arkansas
Fayetteville, AR

Ryan Van Roekel
University of Arkansas
Fayetteville, AR

Mike Vayda
University of Arkansas
Fayetteville, AR

Hank Venema
International Institute for Sustainable Development
Winnipeg, MB

Ray Vester
E&M Farms
Stuttgart, AR

Lauren Vitko
The Pennsylvania State University
State College,PA

Dave Warner
Pioneer Hi-Bred International, Inc.
Johnston, IA

Reagan Waskom
Colorado State University
Fort Collins, CO

Clarence Watson
University of Arkansas
Fayetteville, AR

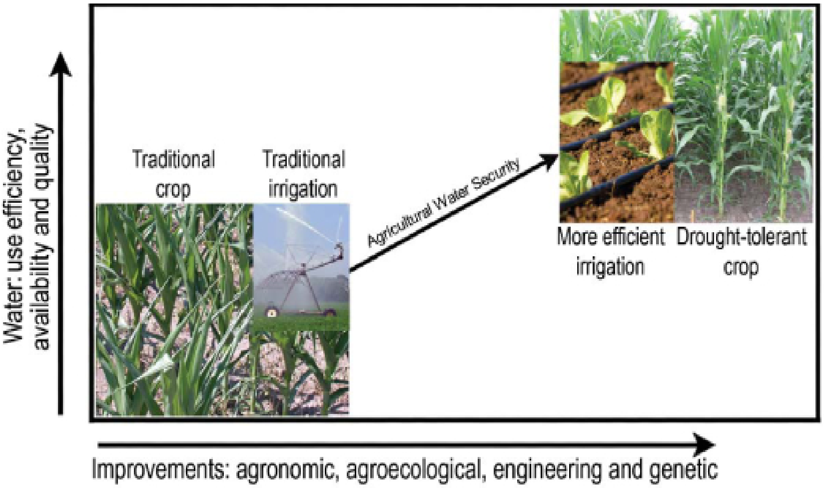
Hongshun Yang
University of Minnesota
St. Paul, MN

David Zilberman
University of California
Berkeley, CA

# APPENDIX

# Appendix

## Agricultural Water Security: Research and Development Prescription for Improving Water Use Efficiency, Availability and Quality[1]




"Water is the staff of life."

—Traditional saying

"Our water crisis should occasion grave concern but not panic. We have solutions available; now we need a national commitment to pursue them."

—Robert Glennon (2009)[2]

---

[1] In Canada and the United States.

[2] Glennon R (2009) Unquenchable: America's Water Crisis and What To Do About It. Washington, DC: Island Press. Photographs by permission of: (crops) Drs. Kevin Steffey and Michael Gray (University of Illinois at Urbana-Champaign and the University of Wisconsin-Madison); (irrigation systems) Dr. H. Perlman (US Geological Survey) and iStockphoto LP.

National Agricultural Biotechnology Council
B 15 Boyce Thompson Institute
Tower Road
Ithaca, NY 14853
607-254-4856 Fax-254-8680 nabc@cornell.edu
http://nabc.cals.cornell.edu/

*Providing an open forum for exploring issues in agricultural biotechnology*

December 31, 2010

The National Agricultural Biotechnology Council (NABC), a consortium of over thirty major agricultural research and educational institutions in the United States and Canada, has developed *Agricultural Water Security: Research and Development Prescription for Improving Water Use Efficiency, Availability and Quality*. This document outlines the challenges of agriculture's need for water (on average one liter of water for every Calorie of food consumed) and its impact on water quality. Research, development and implementation prescriptions are suggested for improving agriculture's efficiency of use of water, expanding the supply of water for agriculture and reducing agriculture's impact on water quality.

NABC identifies water as a critical issue for agriculture. This document and NABC's annual conference in 2012 provide a summary and an open-forum report on needed action.

Bill F. McCutchen
Associate Director
Texas AgriLife Research
Texas A&M University System
College Station, TX 77843

Ralph W.F. Hardy
President
NABC
Boyce Thompson Institute
for Plant Research, Inc.
Ithaca, NY 14853

# Summary

The major and growing challenge for society is water. Water is essential for agriculture. Agriculture uses 70–80% of withdrawn fresh water. The global need by 2050 for increased food/feed production for 3.0 billion additional humans and for increased meat consumption in emerging economies coupled with the biobased industrial product opportunities will greatly expand agriculture's need for water. Climate change also will impact water and agriculture. The effects of crop and animal production on water quality—nutrient and pesticide contamination and soil salinization—need to be reduced to meet increasingly stringent quality standards. Expanded, integrated, focused agronomic, agroecological, engineering and genetic research, development and implementation are essential to improve water-use efficiency, availability and quality as prescribed here for agricultural water security and food security for Canada and the United States.

# Introduction

Water has always been an important issue for agriculture; it is now critically important. Improvements in water use and availability must be achieved to meet the food and feed needs of the projected 9.5 billion humans by 2050 and to provide biofeedstocks for the expanding biobased industrial products market. Simultaneously, agriculture's impact on water quality—via fertilizers, animal waste products, pesticides and salinity—must be reduced to meet the increasingly stringent water-quality standards. This paper outlines the water-related challenges faced by agriculture and identifies research and development opportunities for improving quality and increasing efficiency of use and availability, focusing on the United States and Canada[1]. Policy for water use (*e.g.* CAST 2009[2]) and changes by society and industry outside of agriculture are not addressed.

# Challenges

## Agriculture's Need for Water

Agriculture's need for non-saline water is huge, critical, and growing, as documented by the following:

- 70% to 80% of withdrawn fresh water is used by agriculture, whereas 20% to 30% is used by industry and directly by humans and municipalities.
- Yield of plant-based rain-fed agriculture is limited to a significant extent by less-than-optimal availability of water during the growing season, from brief spells of moisture stress to periodic major droughts. Optimum yield is restricted by up to 50% or more by limitations in water and solar radiation.
- Most plant species are highly inefficient users of water. Major crops—wheat, soybean, *etc.*—transpire through stomata over 150 molecules of water for each net molecule of $CO_2$ captured by photosynthesis.
- Food production requires large amounts of water. A rule of thumb is that 1–2 liters of water are used to produce one food calorie (Cal), *i.e.* about 500–1,000 gallons of water every day for an average daily ration of 2,500 Cals. However, the range is large. For example, production of 1 kg of wheat requires between 400–2,500 liters depending on variety, fertilization, moisture stress and management. This range of values provides hope for improvement in efficiency. Almost all of the water needed for meat and milk production is used to provide feed for livestock and is not directly consumed by the animals.
- Projected world population growth to 9.5 billion by 2050, coupled with increased meat consumption by people in emerging economies such as China, will greatly increase the need for water for food and feed production by agriculture; alternatively, dietary choices will be restricted by water limitations.
- Different agricultural production systems—*e.g.* large-scale traditional, genetically engineered crops, organic and locally produced—may require different prescriptions for improving water-use efficiency and reducing their environmental footprints, although the major water requirement for each will be for primary plant production and, therefore, similar.
- The United States and Canada—as exporters of corn, soybean, wheat, canola, *etc.*—are, effectively, major providers, not only of food and feed but also indirectly of water, to other parts of the world.
- Major new industrial product opportunities for agriculture, in the biobased or green economy, will require water to grow dedicated biomass crops—switchgrass, miscanthus, sorghum, algae, *etc.*—as well as for processing to fuels, chemicals and materials.
- Irrigation for agricultural crop production is essential in low-rainfall regions of the world, *e.g.* South Asia, the Middle East and North Africa. Although irrigation is used on less than 20% of agricultural land in the United States and even less in Canada, in some areas it is critical, *e.g.* the Central Valley of California, Arizona and the High Plains states. Half of the fruits and vegetables consumed in the United States come from irrigated fields in California. Years of increasing irrigation and urbanization are challenging water security in these areas. Groundwater aquifers are being depleted in the High Plains. Surface water sources are being fully used in Cali-

---

[1] Several *NABC Reports* contain presentations that address aspects of agriculture and water, *e.g.* *16*, *19*, *20* and *21*. The 2012 conference will focus on agriculture and water.

[2] Council for Agricultural Science and Technology (CAST) (2009) Water, People, and the Future: Water Availability for Agriculture and the United States. Issue Paper 44. Ames, IA: CAST.

fornia and Arizona, such that agriculture is in growing competition with industrial, environmental and ecological, recreational and expanding urban users.

- Desertification is increasing globally, but almost exclusively outside of Canada and the United States.
- Global climate change is projected to have negative and positive effects on agriculture, depending chiefly on geographical location. Weather extremes will increase in intensity and frequency, including temperature and rainfall; some areas will become wetter, some drier. It is projected that southern latitudes will be less favorable for crop production whereas northern latitudes, *e.g*. the Canadian prairies, may be more favorable[1,2].

### Agriculture's Impact on Water Quality

Agriculture, both intensive grain and animal production, has negative impacts on water quality as do industrial and municipal uses. Contamination of water—ground, rivers, lakes—with fertilizer, nutrients and other components of animal waste, and pesticides, is a problem. Salination is a byproduct of irrigation and fertilization.

- Fertilization is essential for high-yield grain production, *e.g*. corn and wheat. Up to 40% of fertilizer N (and other applied nutrients) are not taken up and eventually some enters rivers, lakes, groundwater and coastal waters, producing algal blooms and depleting oxygen levels. These hypoxic or dead zones are significant; in 2009, the hypoxic zone in the Gulf of Mexico was estimated at 3,000 square miles. The EPA has identified over 6,000 bodies of water in the United States, of which the quality is impaired by excessive nutrient content.
- Concentrated animal production—feedlots, large dairy facilities, poultry houses and swine farms—require management of waste nutrients and reduction of contamination of water.
- Pesticide, including herbicide, use—regulated by EPA in the United States and Health Canada's Pest Management Regulatory Agency in Canada—is standard practice for most plant agriculture. Weed control with herbicides eliminates the water lost to weed growth, and, similarly, pest control improves the efficiency of water use in food and feed production. Some of the early pesticides, *e.g*. the herbicide atrazine, were degraded only slowly and reached groundwater. Pesticide-detection systems have become highly sensitive and the significance of low-level, but now detectable, pesticide residues in water has become a controversial issue.
- Intensive irrigation and fertilization can increase the salinity of soil (and of groundwater), negatively affecting crop production.
- Erosion after conventional tillage leads to loss of topsoil to rivers causing contamination, not only with particulates, but also with agricultural chemicals carried by the soil.
- Water flows, necessary for ecological and ecosystem functions, directly compete with agriculture.
- Numeric nutrient water-quality standards for lakes, rivers and reservoirs are being developed and will increasingly impact agricultural production systems.

Although impacts by agriculture on water quality probably will never be completely eliminated, significant progress is being made, and this effort must continue.

The above challenges dictate expanded research and development efforts in Canada and the United States to increase water availability and use efficiency in agriculture and decrease adverse impacts on water quality.

## Research and Development Prescriptions

### Improving Agriculture's Water Use

The opportunities for improving the efficiency of water use by agriculture are genetic, agronomic including agroecology, engineering, and possibly chemical. Genetic approaches have significant potential with traditional plant breeding being supplemented with molecular genetic approaches. The first commercial product—drought-tolerant corn—is scheduled for farmers' fields in 2011. Agronomic and agroecological approaches are well established, *e.g*. conservation tillage and improved methods of delivering/managing irrigation water, but there is great potential for water savings through improved irrigation, management and other technologies. Chemical applications may mini-

[1] Eaglesham A *et al*. (Eds.) (2009) NABC Report 21: Adapting Agriculture to Climate Change. Ithaca, NY: National Agricultural Biotechnology Council.

[2] Bates BC *et al*. (Eds.) (2008) Climate Change and Water. Technical Paper VI of the Intergovernmental Panel on Climate Change. Geneva: IPCC Secretariat.

mize negative responses of crops to brief periods of water shortage.

### *Genetic, Agronomic, Agroecological, Engineering and Chemical Approaches*

Research on the effects of abiotic stresses on plants, including drought, is increasing. For example, the *HARDY* gene, when expressed in rice, improves water-use efficiency by increasing photosynthetic assimilation while reducing transpiration; the *cspB* gene is an example from corn. Several plant-breeding companies have disclosed plans to market corn with increased drought resistance and improved yield stability. Industry will probably extend this initial breakthrough in improved water-use efficiency and drought tolerance to other major-acreage crops—soybean, wheat, cotton—whereas lower-acreage crops—barley, oats, horticultural products—will probably require public-sector R&D. In addition, public-sector research probably will be a major identifier of relevant genes to enable improved drought tolerance and increased water-use efficiency. Irrigation of perennial vine and tree crops will, in the near future, benefit more from appropriate timing of water applications than from genetics.

The above genetic examples of improved drought tolerance employed traditional breeding and selection of genes found in model plants or bacteria. Another genetic approach is to study species that are inherently more drought tolerant, such as sorghum. The genetic basis for sorghum's relative tolerance of moisture deficiency is being elucidated by comparison of its genomic sequence with those of more drought-sensitive plant species. A longer-term, more-high-risk possibility is to increase water-use efficiency by conversion of crops with $C_3$ photosynthesis—wheat, soybean, rice, *etc*.—to become $C_4$ photosynthesizers like corn and sorghum, although over thirty years of genetic and chemical attempts in this endeavor have been unsuccessful. However, the exploding, massive database and availability of new tools with more interdisciplinary approaches are reigniting this approach with the possible production of intermediate $C_3/C_4$ crops. A related approach is the study of the genetic and biochemical pathways of CAM species, *e.g*. the common ice plant (*Mesembryanthemum crystallinum*) and pineapple that have water-use efficiencies of up to ten times those of major crop plants. These plants absorb and store $CO_2$ during darkness and release it slowly during the day, thus reducing transpiration so that they thrive in hot, dry conditions.

Also possible is the development of crops that are grown at times when evapotranspiration demands are low. For example, rapidly maturing annual crops that are planted earlier or later would avoid maximum summer water loss.

Application of specific chemicals may mitigate the effects of drought. An example of a possible product is an ethylene inhibitor that protects plants from the effects of moderate moisture deficiency. Another example is stimulating production of the plant hormone abscisic acid to decrease stomatal opening, thereby reducing transpiration. A beneficial byproduct of future elevated atmospheric $CO_2$ levels will be increased stomatal closure, thereby reducing transpiration and increasing water-use efficiency.

Significant genetic variation in crop plants has been identified to reduce transpiration, such as waxy covering on leaf surfaces and more-efficient stomatal responses to water stress, and longer, more-branched roots and more-dense and longer root hairs for more efficient uptake of water and nutrients.

An advantage of abiotic-stress resistance versus biotic-stress resistance is that genetic and chemical solutions to abiotic stress should be long-lived, whereas resistance almost always develops to biotic stress products, both genetic and chemical.

The benefits from agronomic, agroecological and engineering-improved water use are well established and there is major opportunity for more in the future. Substantial contributions to date include:

- tillage modifications—from deep plowing to minimum till to vertical till or no till to improve soil structure,
- expanded use of cover crops,
- improvement in irrigation-water delivery and use from inefficient flood and furrow to precision irrigation, lined irrigation ditches, drip irrigation and micro-sprinklers,
- hydroponics for intensive vegetable production.

Potential future benefits include:

- soil-moisture sensing (*in situ* and remote) to guide management practices,
- mathematical modeling of crop-water requirements,
- precision agriculture,
- integrated cropping systems,
- management of complex soil water properties to enhance crop productivity,

- salt-water management in the root zone,
- irrigation technology including water-system automation to achieve water savings,
- irrigation water capture and reuse from development of new technologies and control systems,
- soil amendments for improved water-use efficiency, *e.g.* incorporation of long-lived biochar,
- drainage and water-quality management to improve water quality,
- integrated climate and land-use hydrologic-agroecological modeling systems for optimal location of agricultural lands in watersheds to maximize yield and natural assimilation capacity to minimize excess nutrients from agricultural production.

Some of the above will benefit both water-use efficiency and water quality.

### Availability—Salt Tolerance and Reuse to Expand the Supply of Water for Agriculture

Fresh water constitutes 2% of the global supply, whereas 98% is saline. Development of crops tolerant of saline water is the major opportunity (for salinity); economically feasible desalination of water would hugely expand the supply of water for humans, but may still be too expensive for agriculture.

Land plants evolved from halophytes, but, in the process, lost their tolerance of salinity. However, there is significant variability in salinity tolerance of some crop plants, *e.g.* rice. Genetic approaches have increased salinity tolerance in tomato. Improving salinity tolerance of crops by 20% to 30% through traditional and molecular genetic breeding would have global impact, as productive acreage could be expanded and low-quality water employed for food production, allowing fresh water to be used to meet human and environmental needs.

Use of low-quality water, *e.g.* brackish or reclaimed water, for irrigation of feed crops and industrial uses represents an opportunity to expand the water supply for food production. Supplementing tree crops with low-quality water at certain times of the year is another possibility. However, water used to grow food crops, *e.g.* fruits and vegetables, must be safe at certain periods so as not to contaminate the harvested entity.

Research is needed to develop cost-effective wastewater and reuse options for suburban landscapes and agriculture. Sustainable water-management strategies will increasingly require more immediate reuse for all purposes.

### Reducing Agriculture's Impact on Water Quality

#### *Nutrient Contamination*

Unused and waste nutrients from crop and animal agriculture can lead to contamination of rivers, lakes and groundwater. Nutrient management in crops is improving, *e.g.* corn used to require about 1.2 lb N fertilizer per bushel, whereas the current target is 0.75 lb. Fertilizer nitrogen delivery is being micro-managed to maximize crop recovery, driven in part by the need to minimize input costs. Geneticists are developing crops with increased nitrogen-use efficiency. In the long term, a high-reward/high-challenge research opportunity is self-nitrogen-fertilizing non-legume crops, thereby eliminating unused nitrogen and most of the nitrogen contamination problem in water from crop production. One revolutionary futuristic approach, potentially achievable with today's molecular tools is to induce crop plants to form ste*m no*dules containing rhizobia with photosynthetic capability (similar to those that nodulate the stems of Aeschynomene specie*s), thereby* eliminating the large energy draw from the plant to support biological nitrogen fixation in root nodules of today's legume and tomorrow's non-legume crops. In addition to the huge benefit to water quality, these would bring a major reduction in agricultural use of energy to synthesize fertilizer nitrogen.

Waste nutrients from animal agriculture are being recycled to soils under protocols that limit water contamination. Low-phytate plants, animals producing phytase—*e.g.* the Enviropig™ —and phytase-supplemented feeds are being commercialized to reduce phosphate content in animal waste and minimize contamination of rivers and lakes.

#### *Pesticide Contamination*

Herbicide- and pest-resistant crops have less environmental impact on water, as well as direct reduction in water contamination by reduction in herbicide and insecticide sprays or use of compounds with faster degradation, *e.g.* glyphosate versus atrazine. A recent NRC report suggests that the major benefit from commercial transgenic crops is environmental[3], but the increase in gyphosate-resistant weeds is a concern.

[3] National Research Council (2010) The Impact of Genetically Engineered Crops on Farm Sustainability in the United States. Washington, DC: The National Academies Press.

8

# Conclusion

There are multiple agricultural research and development opportunities to improve water availability, efficiency of use, and quality—genetic, agronomic, agroecological, engineering and chemical. Immediate, expanded, integrated and focused R&D investment by the public and private sectors—in genetics, chemistry, agronomy, agroecology and engineering—is our recommended prescription for agricultural water security and food security in the United States and Canada.

BOYCE THOMPSON INSTITUTE
David Stern
President

CORNELL UNIVERSITY
Margaret E. Smith
Associate Director,
Cornell University Agricultural Experiment Station

MICHIGAN STATE UNIVERSITY
Steven G. Pueppke
Director, Michigan Agricultural Experiment Station and
Associate Vice-President for Research and Graduate Studies

NORTH DAKOTA STATE UNIVERSITY
Ken Grafton
Dean, College of Agriculture, Food Systems, and
Natural Resources and Director, North Dakota
Agricultural Experiment Station

OREGON STATE UNIVERSITY
Lawrence R. Curtis
Associate Dean,
College of Agricultural Sciences

PURDUE UNIVERSITY
Marshall Martin
Senior Associate Director of Agricultural Programs
and Assistant Dean of Agriculture

THE PENNSYLVANIA STATE UNIVERSITY
Bruce A. McPheron
Dean, College of Agricultural Sciences

UNIVERSITY OF ALBERTA
John J. Kennelly
Dean, Faculty of Agricultural, Life
and Environmental Sciences

CLEMSON UNIVERSITY
Susan F. Barefoot
Chief Operating Officer,
Clemson University Experiment Station and
Associate Dean, Food Safety and Nutrition

MCGILL UNIVERSITY - MCDONALD CAMPUS
Chandra A. Madramootoo
James McGill Professor and Dean, Faculty of Agricultural
and Environmental Sciences

NORTH CAROLINA STATE UNIVERSITY
Kenneth R. Swartzel
Coordinator,
Bioprocessing Programs, College of Agriculture
and Life Sciences

OHIO STATE UNIVERSITY
Steven A. Slack
Associate Vice President for Agricultural Administration
and Director, Ohio Agricultural Research and Development
Center

OKLAHOMA STATE UNIVERSITY
Clarence E. Watson
Associate Director,
Agricultural Experiment Station

SOUTH DAKOTA STATE UNIVERSITY
THOMAS CHEESBROUGH
Interim Director, Agricultural Experiment Station

TEXAS A&M UNIVERSITY
Bill F. McCutchen
Associate Director,
Texas AgriLife Research

UNIVERSITY OF ARIZONA
Eugene Sander
Vice Provost and Dean, College of Agriculture
and Life Sciences

University Of Arkansas
Mark J. Cochran
Associate Vice President for Agriculture-Research and Director, Arkansas Agricultural Experiment Station, Division of Agriculture

University of connecticut
Gregory Weideman
Dean and Director,
College of Agriculture and Natural Resources

University of California-Davis
Neal Van Alfen
Dean, College of Agricultural and Environmental Sciences

University of Florida
Mark R. McLellan
Dean for Research and Director,
Florida Agricultural Experiment Station

University of Georgia
Robert N. Shulstad
Associate Dean for Research,
College of Agricultural and Environmental Sciences

University of Guelph
Robert Gordon
Dean,
Ontario Agricultural College

University of Kentucky
Nancy M. Cox
Associate Dean for Research and Director, Agricultural Experiment Station

University of Illinois at Urbana-Champaign
Jozef L. Kokini
Associate Dean of Research and
Director, Illinois Agricultural Experiment Station

University of Manitoba
Michael Trevan
Dean, Faculty of Agricultural and Food Sciences

University of Minnesota
F. Abel Ponce de Leon
Senior Associate Dean for Research and Graduate Programs,
College of Food, Agricultural and Natural Resource Sciences
and Associate Director, MAES

University of Missouri at Columbia
Marc J. Linit
Associate Dean for Research and Extension,
College of Agriculture, Food and Natural Resources

University of Nebraska-Lincoln
David Jackson
Associate Dean,
Agricultural Research Division

University of Saskatchewan
Graham J. Scoles
Associate Dean for Research,
College of Agriculture and Bioresources

University of Wisconsin
Molly Jahn
Dean,
College of Agriculture and Life Science

Washington State University
Ralph P. Cavalieri
Associate Dean, College of Agricultural, Human, and Natural Resource Sciences and Director, Agricultural Research Center

This document was not signed by the NABC member from the USDA

National Agricultural Biotechnology Council

B 15 Boyce Thompson Institute
Tower Road
Ithaca, NY 14853
607-254-4856 Fax-254-8680 nabc@cornell.edu
http://nabc.cals.cornell.edu/

*Providing an open forum for exploring issues in agricultural biotechnology*

National Agricultural Biotechnology Council*
Boyce Thompson Institute, B 15
Tower Road
Ithaca, NY 14853

607-254-4856    fax-254-8680
nabc@cornell.edu
http://nabc.cals.cornell.edu

RALPH W.F. HARDY, PRESIDENT

ALLAN EAGLESHAM, EXECUTIVE DIRECTOR

SUSANNE LIPARI, EXECUTIVE COORDINATOR

*Member institutions are listed on page v.