



Proceedings of the 2010 Water for Food Conference

Lincoln, Nebraska – May 2-5



water  
for  food

A GLOBAL INSTITUTE AT THE UNIVERSITY OF NEBRASKA

Proceedings of the 2010  
Water for Food Conference

Lincoln, Nebraska – May 2-5

UNIVERSITY OF  
Nebraska

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Proceedings of the 2010 Water for Food Conference, May 2-5, Lincoln, NE.

**Citation:**

University of Nebraska–Lincoln Office of Research and Economic Development (2010).  
Proceedings of the 2010 Water for Food Conference. Lincoln.

ISBN: 978-0-615-41249-8

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## In Memoriam



**Robert B. Daugherty**  
Jan. 8, 1922 – Nov. 24, 2010

*“Improving agricultural productivity has been my life’s work.”*

## **\$50 Million Gift from Robert B. Daugherty Foundation Funds Water for Food Institute**

On April 20, 2010, the University of Nebraska announced a \$50 million founding gift commitment from the Robert B. Daugherty Charitable Foundation to support the global Water for Food Institute, a research, education and policy analysis institute focused on the efficient use of water in agriculture.

NU President James B. Milliken said the gift will enable the university to become a global resource for developing solutions to the challenges of hunger, poverty, agricultural productivity and water management. “By 2050, the world’s population will increase by 40 percent and demand for food – produced with finite amounts of land and water – will double,” Milliken said. “We have the experience and opportunity to build a global center in Nebraska, leveraging the knowledge and resources of the University of Nebraska and other leading institutions to help alleviate human suffering and food insecurity.”

Milliken praised the vision and commitment of Robert B. Daugherty, founder of Valmont Industries, who created the most successful irrigation company in the world and remained committed to the efficient and sustainable use of water to feed a growing world population. “Bob Daugherty was a true pioneer and visionary,” Milliken said. “He helped transform production agriculture and was a leader in addressing one of the most critical challenges facing the world.”

When the gift was announced in April, Daugherty said, “I have great faith in the University of Nebraska and its ability to make this institute a place where the best minds come together to find solutions that will improve the quality of life for people around the world through the strategic and responsible use of water.”

The Water for Food Institute is committed to helping the world efficiently use its limited fresh water resources to ensure the food supply for current and future generations. The institute will offer research, education and policy analysis on the efficiency and sustainability of water use in agriculture, the quantity and quality of water resources, and human issues that affect the water decision-making process.

Issues surrounding water for food have long been, and continue to be, a focus of University of Nebraska research. The knowledge and capabilities developed in Nebraska can be shared and applied globally, and Nebraska can, in turn, learn from its regional, national and international partners, Milliken said.

The water for food institute is governed by a board of directors: James B. Milliken, president, University of Nebraska, chairman; Mogens Bay, chairman of the board, Robert B. Daugherty Charitable Foundation, and chief executive officer, Valmont Industries; and Jeff Raikes, CEO, Bill & Melinda Gates Foundation.



# Foreword

Today 75 to 80 percent of human water consumption is used to grow food. The projected doubling in food demand, coupled with the impact of climate change on the geographic availability of water, will significantly increase the demand for water and the potential for a water crisis.

As native Nebraskans, we know very well the linkage between water and food. We grew up in an agricultural state, in an environment with an abundance of good soil, enough rainfall and water for irrigation, and the constant expansion of agriculture through innovation. As the threat of global poverty and food insecurity grows, we know that water security and food security are inextricably linked. Without adequate water resources, we cannot meet the needed increase in food production. We must grow more “crop per drop.”

This was the key issue at the 2010 Water for Food Conference: Growing More with Less, hosted by the University of Nebraska with the support of the Robert B. Daugherty Charitable Foundation, the Bill & Melinda Gates Foundation and Monsanto

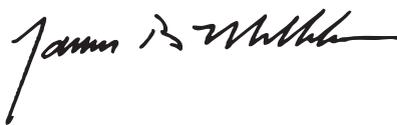


Jeff Raikes, CEO  
Bill & Melinda Gates Foundation

Company. This report documents the ideas and discussions that emerged from that conference.

Two weeks before the conference convened, fellow Nebraskan Robert B. Daugherty showed his commitment to the efficient and sustainable use of water to feed a growing world population with a founding gift of \$50 million from his foundation to the University of Nebraska to establish the global Water for Food Institute. As founder of Valmont Industries, the most successful irrigation company in the world, Daugherty played a role in transforming production agriculture and was a leader in addressing one of the most critical challenges facing our world. His gift creates an opportunity for the University of Nebraska to make a lasting impact on global poverty and hunger.

The conference provided a forum to bring together more than 300 people from 13 countries who share our urgent interest in finding innovative solutions to the challenge of growing more food with less water. We hope this report inspires you to consider your contribution to growing more with less.



James B. Milliken, President  
University of Nebraska





## EXECUTIVE SUMMARY

## Executive Summary

“I see the linkage of the water crisis and the future of global poverty, yet I don’t see the general awareness of this issue. Finally, after 25 years of tragically reduced investment in agricultural development, we hear the talk of food security; we see significant increases in the investment that is necessary. Yet I don’t hear the talk of securing water for food,” Jeff Raikes, chief executive officer of the Bill & Melinda Gates Foundation, said in his keynote address at the 2010 Water for Food Conference.



Nathan Laurell/Flickr

Carrying water in Mali

Hosted by the University of Nebraska with the support of the Robert B. Daugherty Charitable Foundation, the Bill & Melinda Gates Foundation and Monsanto Company, the conference brought together more than 300 scientists and decision-makers from universities, the private sector, governments and nongovernmental organizations around the world to discuss the challenge of growing more food using less water.

Raikes concluded in his keynote address: “If we don’t change, if we don’t innovate across the spectrum of all the levers that we can pull, if we don’t take an integrated, interdisciplinary approach to this challenge, we are not going to be able to feed the world.”

The need to use all available tools – technological, political, societal and institutional – was echoed throughout the conference and reflected in the diversity of topics, perspectives and expertise represented.

### Innovating Across the Spectrum

The Gates Foundation is concerned about water-scarce areas, Raikes said, because that is where people are hungriest and global poverty is greatest. Business as usual will not suffice in overcoming water shortages, and although Raikes observed limitations in applying past solutions to the future, he also expressed optimism that we can achieve food security for all people by combining the best practices of today – such as seed technology, market access and soil management – with advances to come, particularly in helping small farmers by developing affordable water storage, pumps and micro-irrigation technologies. Policies, including incentives that provide adequate water resources for farmers, also will be key.

Pedro Sanchez of Columbia University’s Earth Institute demonstrated that tripling Africa’s rainfed cereal crop production from 1 ton to 3 tons per hectare is not only possible, but achievable. It can be accomplished without increasing water use by reducing losses from evapotranspiration at higher plant densities of 3 tons per acre. “This is what I would like to call the Green Revolution bonus,” Sanchez said. “As you go from 1 to 3 tons per hectare, you can get a lot more water.” Successes in Malawi and the Earth Institute’s Millennium Villages project have shown that distributing fertilizer and seed increases production dramatically. These successes have led to the Global Food Security

Trust Fund, a global fund for smallholder agriculture. “I’d like to redefine the goal of the Green Revolution as going from 1 to 3 tons per hectare,” Sanchez said. Sanchez also described efforts to create a digital soil map of the world to better manage local needs by, for example, pinpointing areas requiring additional nutrients or erosion control and identifying regions with a higher probability of drought stress.

David Molden of the International Water Management Institute (IWMI) urged prioritizing water access for the poor, ecosystem enhancement and improved water governance. He reinforced Sanchez’s point that the greatest opportunity lies in low-yield agriculture; increasing yields from 1 ton to 2 tons per cubic meter of water increases water productivity 74 percent. “This is the area for the biggest potential. ... This is also the area where there’s high poverty. If we can go and narrow in on that focus, we get two big wins all at the same time.” Rather than focusing on the distinction between rainfed and irrigated agriculture, Molden encouraged looking at appropriate available solutions in a given location as well as considering large-scale innovative solutions. He offered six problem sets for the future: 1) upgrade rainfed systems with better water and soil management; 2) revitalize under-performing irrigation systems; 3) learn to manage groundwater sustainably; 4) reuse urban wastewater safely; 5) transform water governance and management; and 6) improve information systems.

*“I see the linkage of the water crisis and the future of global poverty, yet I don’t see the general awareness of this issue.”*

Irrigation must play a large role in a future Green Revolution for Africa, said Ken Cassman of the University of Nebraska–Lincoln (UNL). The 1960s Green Revolutions in Asia and Nebraska relied primarily on irrigation, which allowed

both areas to successfully and dramatically increase productivity, Cassman said. “If [Sub-Saharan African] agriculture is much more like the harsher rainfed environments of the western Corn Belt, can rainfed agriculture do it alone?” he asked. Sub-Saharan Africa has sufficient water resources to

support irrigation, which in turn provides stable yields and generates income to support investment in associated industries and infrastructure.

Although irrigation maximizes yields, greatest net income occurs below maximum yields after factoring in additional water costs, said Richard Cuenca of the National Science Foundation (NSF). What incentives, he asked, can be used to encourage growers to consider other objectives besides reaching maximum production? Cuenca also cautioned that climate change will undoubtedly affect future food production, although models disagree by how much. An International Food Policy Research Institute study predicted that by 2050, food production of major rainfed and irrigated cereal crops will decline 13 to 42 percent, eliminating progress made in lowering child malnutrition rates.

John Briscoe of Harvard University noted the many changes and advances occurring worldwide.

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The West's investment in agricultural research and water infrastructure projects has dwindled. Some middle-income countries, such as Brazil, are having great success financing their own projects, and China is financing most dam projects in developing countries. In addition, model public-private partnerships are occurring in irrigation, drainage and water supply systems. New technologies, such as genetically modified organisms, are proving revolutionary in many developed and middle-income countries. Sub-Saharan African countries must adopt them as well, Briscoe urged. "We're going to need public leadership and private innovation," he said. "The world doesn't begin and end in the United States anymore. ... The world is out there in China, India, Africa, Brazil. These are places with enormous intellectual capability, where they're able to actually innovate often much faster than we are."

### Country Case Studies

Visitors from several countries shared innovative research and reforms happening in their countries, offering insights and challenges for the future. Shiqi Peng of China's Ministry of Agriculture described China's experiences implementing an irrigation strategy designed to save water. China struggles with geographic and temporal imbalances in water resources. Despite irrigation improvements, inappropriate management continues to cause problems. The government's strategy includes infrastructure construction, water management improvements, modern irrigation equipment and rainfed technology to take advantage of rainfall on irrigated land. As a result, irrigated land has expanded, and grain production and water use efficiency have improved without increasing agricultural water use.



Chinese farmer in wheat field

However, future demands to increase agricultural production, particularly of cash crops, will further stress China's agricultural system. "We have a long way to go," Peng said, but by working with other countries, China hopes to continue improving water management and promoting sustainable agricultural development.

India also has successfully begun reforming irrigation management, said U.N. Panjiar, secretary of India's Ministry of Water Resources. Like many places, India faces significant water supply shortages from additional food demands and deteriorating infrastructure. Two major problems have plagued India's irrigation system: poor use of irrigation facilities due to incomplete projects and inefficient irrigation practices, and inequity in water distribution. To tackle these issues, India has instituted a participatory irrigation-management system through water-users associations. The sense of ownership among farmers ensures sustainability and has resulted in increased water use efficiency and distribution equity, and improved conditions for farmers.

Nguyen Hieu Trung of Can Tho University also recommended including a bottom-up approach to food security in Vietnam's Mekong Delta. Study results demonstrate that rice and fish farmers adjust their practices to cope with current weather variability, but they may not be equipped to deal with future climate change. Adaptive strategies must include top-down and bottom-up approaches, including instituting appropriate policies to enhance farmers' adaptability and giving farmers a choice of technological packages.

Elijah Phiri of the University of Zambia described the Comprehensive Africa Agriculture Development Programme (CAADP) designed to help countries achieve economic growth through agricultural development. Implemented under the African Union, CAADP works at the political

level to improve policies, capacities and investment. It provides a framework to guide countries as they develop their agricultural development plans and priorities in several key areas, including research, market infrastructure and reliable water systems. This framework is driven by a collective desire to make a significant impact on the development agenda in terms of food security and poverty alleviation, Phiri said. "There has been a recognition of a requirement for more than just new money, but also a radical rethinking of how we do business."

In Australia, radical rethinking of water management has led to a sophisticated system of tradable water rights, based not on seniority but on shares held within pools, which has achieved impressive results, said Mike Young of the University of Adelaide. A key step was



Agricultural fields along a river in Australia

## Executive Summary

turning water supply systems over to farmers. Now farmers make more money from selling water when prices are high and water is scarce than from growing low-value crops. This system has resulted in water moving from low-value to high-value uses, dramatic improvements in previously inefficient water-irrigation management districts and farmer-generated innovations that have increased yields and water use efficiency. “The revolutions that have occurred since we’ve [made reforms] have been massive in terms of actual improvement in productivity,” Young said.



Terraced fields in Nepal

In contrast, Afghanistan’s many years of conflict and environmental devastation have severely decreased the country’s water supply and agriculture, John (Jack) F. Shroder of the University of Nebraska at Omaha said. In addition to man-made causes, such as overgrazing and deforestation, powerful winds and mud flows during the monsoon season contribute to environmental problems. Shroder’s work on Himalayan glaciers, which are critically important storehouses of water, has shown the surprising data that some glaciers are growing, although many more are shrinking. As the permafrost warms, rockslides occur, threatening Pakistan,

Afghanistan and other countries with destructive and powerful flooding, particularly during the monsoon. “Change is coming in the Himalayas and Hindu Kush, just like it always has,” he said. “Drought in some places, too much water in others, and the change probably won’t be quite what we expect anyway.”

### Technological Advances

Research continues to produce new technologies and tools to increase agricultural yields while using less water. The conference featured numerous researchers in industry, universities and global organizations working in crop breeding, molecular genetics, computer science and systems modeling, irrigation engineering and other disciplines.

Monsanto Company is committed to doubling U.S. crop production by 2030 while reducing inputs per unit of output, said Robert T. Fraley, the company’s executive vice president and chief technology officer. He cited efforts to advance agronomic practices and breed new varieties, including Roundup Ready® and YieldGard® technologies. Within a few years, the company plans to release a new bioengineered drought-tolerant corn in the U.S. “Clearly, the area that needs this technology the most is Africa,” Fraley said. “I believe that there’s both the opportunity and the need to bring technology that can have tremendous benefit there.” Monsanto has partnered with the International Maize and Wheat Improvement Center (CIMMYT) and others to bring biotechnology to Africa, in an effort funded by the Gates Foundation.

CIMMYT’s Gary Atlin agrees that public-private partnerships, such as those with Monsanto, will

provide improved transgenic varieties for African smallholders, an undertaking that is too expensive for public institutions to do alone. CIMMYT and the International Rice Research Institute also have had tremendous success breeding drought-tolerant corn and rice in rainfed Africa and Asia under managed-stress conditions, which he encourages others to do. New genetic tools will enable even greater advances in breeding. “We need to make sure that farmers in drought-prone environments, the poorest farmers in rainfed regions of the world, are among the first to benefit,” Atlin said.

*“We need to make sure that farmers in drought-prone environments, the poorest farmers in rainfed regions of the world, are among the first to benefit.”*

Richard Richards of Australia’s Commonwealth Scientific and Industrial Research Organisation has released several improved wheat varieties using a trait-based approach. He found it most effective to select each trait under favorable conditions and by phenotype, not genetic markers. He emphasized the need to develop benchmarks for water use efficiency by dispensing with concepts like drought tolerance that are not easily measurable and may be unrelated to productivity.

Roberto Tuberosa of the University of Bologna presented data on research in mapping and cloning quantitative trait loci (QTLs) to increase yields in wheat and maize. He has found QTLs important for drought resistance in *Triticum* wheat and root architecture in corn using forward genetics. “The reason I like the QTL approach is that pretty much we ask the plant what is important,” Tuberosa said. “We do not go in with a preconceived hypothesis.”

A high-resolution water assessment model Marty Matlock is developing at the University of Arkansas could be used to determine how much water corn uses globally and to evaluate the balance between rainwater stored as soil moisture and water from surface or groundwater sources. With a framework for assessing these characteristics, the model can analyze various scenarios, such as climate change and water demand by region.

Matlock also presented for Jason Clay of the World Wildlife Fund, who was ill.

Environmental concerns, such as effluent, fall outside normal market powers and require special incentives and considerations in water resource decisions. “It’s the things that we don’t incentivize, like preservation of riparian zones, that we should perhaps be incentivizing with our limited resources,” Matlock said.

Suat Irmak of UNL described research projects investigating ways to improve agricultural practices that minimize water loss, such as improving evapotranspiration models, developing more efficient center pivot irrigation and studying crop water stress physiology. Irmak emphasized the need to get research results to the farmer, which he is doing through the Nebraska Agricultural Water Management Demonstration Network. Popular with farmers, the network established by Irmak and his colleagues is improving management practices and increasing water use efficiency.

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Advances in irrigation technology and management, such as weather station networks, pressurized irrigation and water use predictions, have been critical to increasing yields and reducing water loss, said Steven R. Evett of the U.S. Department of Agriculture's Agricultural Research Service. He illustrated irrigation benefits with examples from his work in Jordan and Uzbekistan. New technologies, such as mapping yield potential and reusing water, provide opportunities for even greater water use efficiency, he said.

M. Can Vuran of UNL encouraged interdisciplinary research to devise new agricultural solutions. Vuran, a computer scientist, is developing underground wireless sensor networks that may provide real-time information about soil and crop conditions to

above-ground devices, enabling farmers to make immediate, informed decisions about irrigation, improving water use efficiency and yields.

Despite these and other tremendous innovations taking place in universities and other public institutions, the challenge of integrating research into the real world leaves many of these innovations stuck in the laboratory, said Sally Mackenzie of UNL. She described many innovations, particularly in molecular and developmental biology, that have the potential to transform agriculture but are slow to reach commercialization because of the U.S. regulatory process. UNL's Center for Plant Science Innovation hopes to move research into the field by broadening in-house capabilities in crop transformation, facilitating interdisciplinary research and training students to meet these challenges.



Low-pressure sprinkler waters coffee plants in Brazil.

### **Economic Tools**

Richard Perrin and Lilyan Fulginiti, both of UNL, expressed optimism that developing countries are increasing agricultural production to levels required to feed a growing population. Economists predict 1.3 percent annual growth is needed to meet global food requirements in 2050. Using total factor productivity measurements, the economists found that growth rates in the last two decades reached 1.09 percent in Sub-Saharan Africa, 1.5 percent in Central America and 2.5 percent in South America and China. “It seems that developing countries are not slowing down,” Fulginiti said. “They might be ... achieving or closing the gap with the developed countries.” To continue this positive trend, countries need more resources, technologies and investment in agricultural research.

Giulio Boccaletti of McKinsey & Company outlined the results of a McKinsey report that projected a 40 percent water gap between future demands and current capacity, with some areas facing gaps up to 75 percent. He described the water-availability cost curve, an economic tool that determines the cost and potential of various solutions to close the gap, tailored to each country. The tool can be used to identify combinations of solutions and factors in different scenarios, such as climate change and accelerated economic growth. The analysis demonstrates that closing the water gap is possible. He said the problem is not a lack of technology or money, but the need for effective policies, incentives and institutions. “This actually starts framing the choices that policymakers have in thinking about the issue,” Boccaletti said.

### **Support from Government and Public Sector**

Richard Cuenca described several national and international projects supported by the NSF, including the Long-Term Ecological Research sites, the African Long-Term Research Network, northern Kenya’s Mpala Research Centre and the Basic Research to Enable Agricultural Development (BREAD) program in partnership with the Bill & Melinda Gates Foundation. BREAD addresses constraints faced by smallholder farmers in the developing world.

UNESCO-IHE Institute for Water Education supports poor farmers with practical technologies by building capacity through education and research, said the institute’s Krishna C. Prasad. He urged differentiating between developing and emerging countries in considering solutions because their experiences differ substantially; emerging countries, for example, face large urban migration and growing urbanization. IHE emphasizes institutional reform by establishing partnerships, encouraging stakeholder participation and developing innovative educational activities to fill capacity gaps.

Another UNESCO agency, the International Center for Integrated Water Resources Management (ICIWaRM), is the first Category 2 Water Center in the U.S., said the center’s William S. (Will) Logan. It focuses on practical science and technology, including engineering and policy, and partners with universities, organizations and other U.N. agencies in the U.S. and worldwide. The benefits of joining ICIWaRM include an extensive pre-existing network, but it might also somewhat limit freedom of action compared to university centers, Logan said.

# Executive Summary

## A View from Producers

Four producers – two from Nebraska, one from Oregon and one from Argentina – spoke in a panel discussion about their experiences running large farms. The panel focused on changes in farming over the past century and the concerns and opportunities panelists see for using water more efficiently.

Martin Pasman described the growth of his family’s farm in Argentina since 1825. Today, the Pasmans raise cattle, corn, wheat, potatoes and Monsanto seed on 20,000 acres, much of it center pivot irrigated. Early adopters of Roundup Ready® soybeans, Pasman’s family considers no-till farming the cornerstone of their production technology because of the water and labor savings no-till provides.

On his western Nebraska farm that receives about 19 inches of rain annually, Keith Olsen has gone from plowing his rainfed wheat fields and watching rain and wind erode the soil, to growing drought-tolerant corn using no-till and now genetically modified organisms. Olsen is experimenting with new soil management techniques, such as using a stripper head and skip-row planting. He urges fellow farmers to brace for future droughts.

Another western Nebraska farmer, Roric R. Paulman, a self-described early adopter, grows primarily dry beans and popcorn on more than 7,000 acres, much of it irrigated. He is developing a model for measuring consumptive water use to better understand the effects of his water conservation efforts, which will become increasingly important as local utilities limit when and how much water farmers can pump.

“I don’t think we talk enough about consumptive use,” Paulman said. “Now, 300 bushels of corn, that’s great, but in that same respect, I’m going to be asked in my area to reduce my consumption. So can I grow a crop to full capability?”

Because Aaron Madison’s family farm in eastern Oregon receives just 7 inches of rain a year, the family is intensely interested in water conservation. The Madisons irrigate 7,200 acres of their 17,500-acre farm and plant a variety of crops, including a wheat-fallow rotation. The rest is native rangeland for raising cattle. Through Oregon’s innovative Aquifer Storage and Recovery program, the Madisons take water from the nearby Columbia River during high-flow months and store it in a depleted aquifer below the farm until needed.

During the panel discussion that followed, Pasman discussed the changes in Argentina’s tax and trade policy that allowed the country to take advantage of innovations. As a result, production has nearly tripled. He said he would support further policy changes to reduce duty-export taxes on soybeans. Olsen said he’s optimistic that technological advances will help farmers survive future droughts, but he is concerned that too few young people are entering agronomy. He is also concerned that too many government regulations will hurt agriculture’s future. Madison is encouraged by new technological advances, such as variable-rate water and electricity applications. He also described a water conservation project in which Madison Farms collects flooded creek water on its property to store in the aquifer for later use. Every panelist addressed the need to move research from the lab to farmers, both in the

U.S. and elsewhere. An increasing and ongoing exchange of information is vital to tackling the challenge of expanding agriculture with limited water.



Producers Aaron Madison and Keith Olsen answer questions.

### Key Issues for the Future

The conference concluded with a panel discussion on key issues for the future and recommendations for the new Water for Food Institute. Ken Cassman of UNL urged the institute to embrace irrigated agriculture as a significant player in a Green Revolution in Sub-Saharan Africa and to focus on issues important to Nebraska and the rest of the world, such as answering the question of whether high-yield, irrigated agriculture is sustainable.

Nebraska farmer Eugene Glock emphasized the importance of compiling and disseminating information and cautioned against the institute becoming a lobbying agency. He wants it to provide information that helps policymakers make wise decisions.

David Molden of IWMI said the institute can fill the “people gap” by encouraging and training young people in agricultural fields. He also

encouraged the institute to reach outside the U.S., listen to international concerns and help solve global problems.

Peter Rogers of Harvard University reminded participants that global climate change will have tremendous impact on water for food issues and encouraged giving it greater attention. He also emphasized the need to foster accurate and understandable scientific communication through working with journalists and educating faculty who are unfamiliar with agriculture. He also pointed out the important lesson from Australia regarding the need for institutional reform before introducing economic reforms. “I think the important thing there is that the institutions for water management and regulation are absolutely fundamental, if we’re ever to take advantage of the powerful economic tools we have,” Rogers said.

The panelists also encouraged engaging young faculty from a range of disciplines, disseminating information to farmers and reaching out to smallholder farmers worldwide. They discussed the necessary role of private companies, because of the more limited resources of public institutions, but Molden urged the audience to remember that the private sector is not limited to big, international companies, but also includes other countries’ small-scale private enterprises that stimulate local economies. Cassman concluded the discussion by reminding the audience of the important role scientists play in influencing policymakers. Cassman said he believes the institute has a key role in helping those who care about water for food make their case to the world.

1



An aerial photograph of a vast, golden wheat field, showing the repetitive rows of crops stretching across the landscape. The lighting is warm, highlighting the texture of the wheat. At the bottom of the image, there is a dark, semi-transparent wavy graphic element that serves as a background for the text.

# INTRODUCTION

## Introduction

The Future of Water for Food conference in 2009 brought together experts from around the world to discuss the issues and challenges surrounding the use of water for agriculture and to explore the need for an organization with a global perspective and diverse expertise to address these challenges. Building on the enthusiasm of that conference and a generous \$50 million gift from the Robert B. Daugherty Charitable Foundation, in 2010 the University of Nebraska established the global Water for Food Institute, a research, education and policy analysis institute dedicated to helping the world efficiently use its water resources to ensure a sustainable food supply.

The Water for Food Institute is an emerging institute, one that is putting down roots and seeking international collaborations and partnerships. Yet it grows from the University of Nebraska's long history of research leadership in water, agriculture and natural resources management, and the university's willingness to share that critical knowledge not only with Nebraskans, but with the rest of the world. The annual Water for Food conferences are one means of engaging with, and learning from, others who bring decades of experience and perspectives from many disciplines and cultures.

In 2010 the second international conference – Water for Food: Growing More with Less – explored the roles of science, technology, policy and education in developing solutions to the global challenge of doubling world food production under water-limited conditions. This interdisciplinary, multiple-stakeholder conference brought together more than 300 people from 13 countries and included agricultural producers, scientists, scholars and leaders from academic

institutions, business, government and nonprofit organizations. Participants came with a shared concern and urgency about a looming crisis in water and food security. They also brought considerable optimism fueled by the renewed interest and funding in agricultural development, and the dawning recognition in the private and public sectors that the global community is reaching a critical juncture in the management of water resources.



Kenya's Njoro Agricultural Research Station

This was made clear in the keynote address by Jeff Raikes, CEO of the Bill & Melinda Gates Foundation, who issued a call to action, urging that we innovate across the spectrum, invest in and pull on all the key levers, and take an interdisciplinary, integrated approach. "It will be your understanding of this crisis and your vision that leads to greater awareness and inspiring the necessary public and political will to support these investments," Raikes said.

The conference included plenary sessions, technical sessions with presentations and discussions by panels of experts, a panel discussion presenting the views of agricultural producers and a closing panel session. The

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plenary sessions, *Global Perspectives on Water for Food* (Chapter 2), outlined the major topics and challenges, and presented diverse viewpoints from scientific experts and decision-makers, including, among others, Pedro Sanchez, Columbia University Earth Institute and 2002 World Food Prize Laureate; John Briscoe, professor of the practice of environmental engineering and environmental health, Harvard University; David Molden, deputy director general for research, International Water Management Institute; U.N. Panjiar, secretary, Ministry of Water Resources, India; Shiqi Peng, chief scientist, Ministry of Agriculture, China; and Robert T. Fraley, executive vice president and chief technology officer, Monsanto Company.

Concurrent technical sessions focused on four broad areas that are central to the challenge of growing more food with less water. *Genetics and Physiology of Crop Water Use* (Chapter 3) covered global assessment of corn water use, breeding techniques for drought tolerance in cereal crops and the transition of scientific innovations from the laboratory to the field. *Human Dimensions of Water for Food Production* (Chapter 4) featured diverse views, from Australia to Zambia, on the policies and economics of agricultural water use, the world food equation and management of water scarcity. *Technologies and Advances in Water Management* (Chapter 5) explored applications of research and technologies, such as modeling and remote sensing of evapotranspiration, wireless underground sensor networks and irrigation system advances, and their effects on increasing crop water productivity. *Climate Challenges to Water for Agriculture* (Chapter 7) focused on climate effects on water resources and crop production in two key areas:

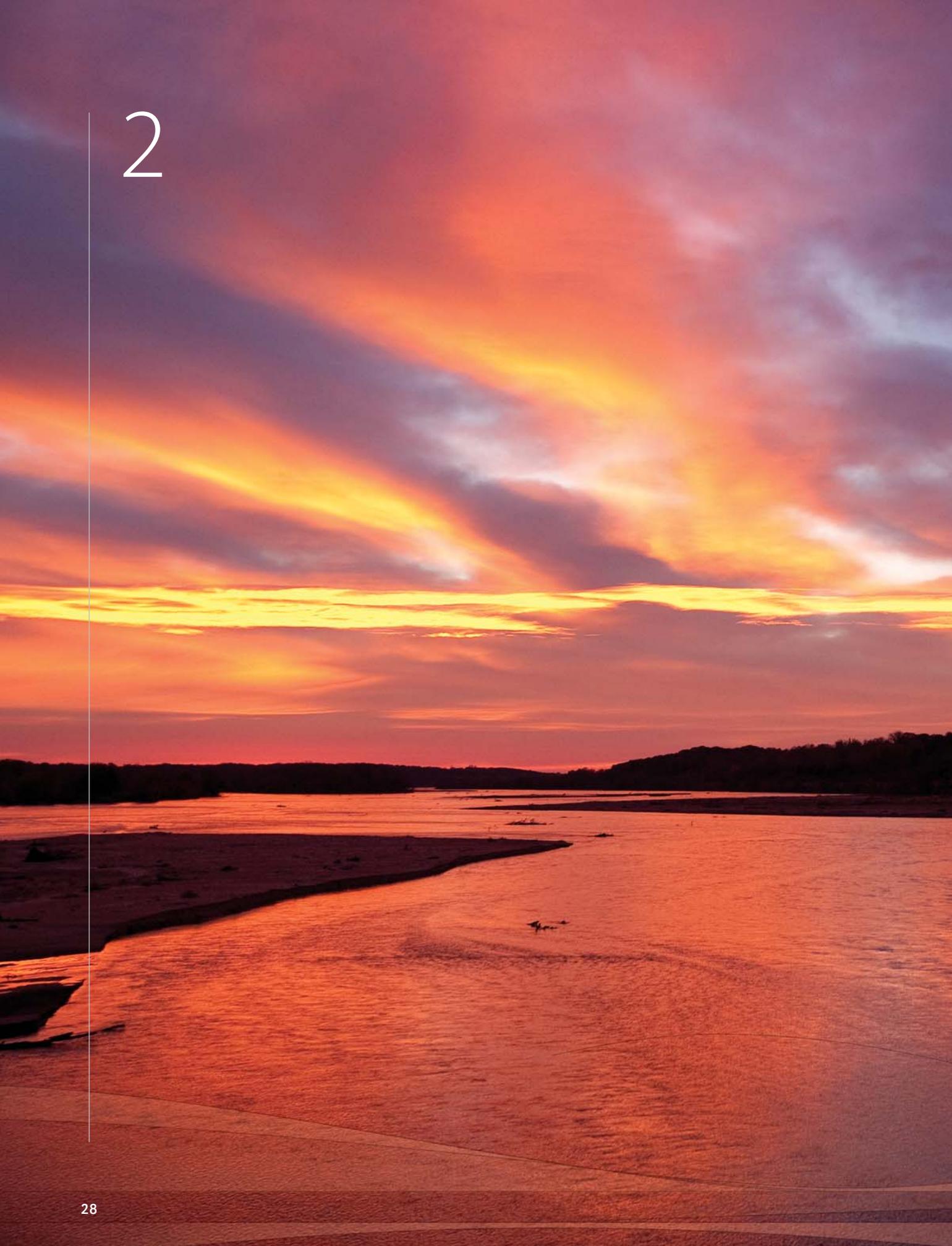
the glaciers of the Hindu Kush and Western Himalayas, and rice and aquaculture production in the Mekong Delta of Vietnam.

Recognizing that even the most innovative research and policy advances are effective only if they are adopted by those who grow our food, the panel, *A View from Agricultural Producers* (Chapter 6), stimulated the most discussion of any conference event. Producers from Nebraska, Argentina and Oregon, who manage irrigated and rainfed systems, discussed the advances in crop production and water management they have implemented from the 1950s until today, as well as the challenges and potential solutions on the horizon.

The closing session, *Key Issues for the Future* (Chapter 8), addressed what participants learned at the conference, goals for the Water for Food Institute during the next three years and perspectives on the most pressing questions facing researchers, producers, policymakers and organizations interested in water issues. The panelists brought together perspectives on crop science, international water management, economics and policy, and agricultural production.

Despite the many disciplines and viewpoints represented at the conference, all participants agreed that the challenges surrounding water for food are urgent and that our search for solutions must include the diverse expertise and experiences of scientists, scholars and decision-makers from all corners of the world. The goal of the Water for Food Institute at the University of Nebraska, and of future conferences, is to build the partnerships and programs that will contribute to those solutions.

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# GLOBAL PERSPECTIVES ON WATER FOR FOOD

# Keynote Address

## The Water Crisis and the Future of Global Poverty

### Jeff Raikes

CEO, Bill & Melinda Gates Foundation

The water crisis will play a major role in the future of global poverty, yet little awareness of this critical issue exists and few discussions are taking place about securing water for food, Jeff Raikes said. In a call to action, Raikes advocated an integrated and interdisciplinary approach, one that pulls on all levers to solve the pending crisis.



Jeff Raikes

### The Crisis

Already about 75 to 80 percent of human water consumption is used to grow food, Raikes said. The projected doubling in food demand, coupled with climate change's impact on geographic availability of water, will significantly increase the demand for water, precipitating a water crisis.

To illustrate the crisis, Raikes, who grew up on a family farm near Ashland, Neb., remembers his father describing the state's wonderful agricultural resources – the rich soils and nearly infinite supply of water. But a photograph of Lake McConaughy in western Nebraska that

shows a boat dock left high and dry far from the lake due to plunging water levels tells a different story. Similarly, a photograph of a dry Jialing River in the shadow of Chongqing, a Chinese city of more than 30 million people, illustrates how urbanization stresses water resources. Industrial water consumption is expected to more than double by 2050. And in a third photograph, a crowd surrounds a large well during a 2003 drought in Natwargadh in India's Gujarat state. "Think about the regional context," Raikes said. "In India, it may be low groundwater levels as the largest problem. In China ... it can be rivers that don't reach the sea."

Raikes compared projections for 2050 to today's food and water needs. Agriculture currently uses about 7 million cubic kilometers of water annually through evapotranspiration to produce the nearly 20 calories consumed daily. By 2050, based on projected food demand from population increases and dietary changes, water requirements will reach 13 million cubic kilometers under a business-as-usual scenario. That figure does not include demands from biofuels.

In addition, water is not where it is needed most, a problem likely to worsen. Raikes said the Bill & Melinda Gates Foundation is particularly concerned about areas of water scarcity, both physical and economic, because the places where water is scarce are the same places where hunger is worst.

Global weather trends are particularly threatening in Sub-Saharan Africa, which is likely to get drier. The way in which climate change will expose itself to the world, the way in which it will become tangible to people, is through a crisis, Raikes said. “My conclusion is that if we don’t change, if we don’t innovate across the spectrum of all the levers that we can pull, if we don’t take an integrated, interdisciplinary approach to this challenge, we are not going to be able to feed the world.”

### Solutions

Given this crisis, what solutions are available? Raikes asked. Some options include:

- Using more land, an unsustainable worldwide solution in the long term.
- Using more water, an option in some areas of Sub-Saharan Africa, but sufficient water may be unavailable or inaccessible.
- Reusing wastewater, an important option for urban farming, but inappropriate for some crops and unable to alleviate much of the water pressure in rural areas.
- Wasting less food, an important but ill-understood option. An estimated 30 to 40 percent of all food produced fails to reach consumers because of post-harvest losses in developing countries and food disposal in developed countries. Less waste, however, can alleviate only some of the water pressure.

Despite these limitations, Raikes expressed optimism. His years spent in the technology world – seeing the power of both innovation in

technology and inspired, passionate leaders working together to change the world – has proven to Raikes that great things can happen.

“Today, I endorse the vision of more ‘crop per drop,’” he said. “We have to get more food on the same land with the same or less amount of water.” Examples proving it is possible exist. “The key question is how can we take what we learn, how can we build new innovations, and how can we bring them together into scalable and sustainable change?”

The gaps between actual and potential yields of rainfed agriculture in Sub-Saharan Africa, in Organisation for Economic Co-operation and Development nations and throughout the world, are large and provide reasons for optimism. According to the International Water Management Institute (IWMI) Comprehensive Assessment overseen by David Molden, investment costs per hectare to upgrade rainfed areas can be relatively low, particularly in Sub-Saharan Africa where



Ethiopian dwelling

## Keynote Address

most rural people live in rainfed areas and where more people can be lifted out of poverty. An optimistic outlook on yield growth demonstrates that achieving 80 percent of potential yield would meet 85 percent of food demand in 2050, particularly in the low-yielding farming systems where poor people tend to live. The IWMI Comprehensive Assessment suggests the world's growing food demand can be met by rainfed agriculture, through yield gains combined with a modest 7 percent increase in agricultural land.

But that scenario is optimistic, and irrigation must be part of the solution, Raikes said. The gap between actual and potential yields in irrigated agriculture also is large. Looking at South Asia, primarily India where 50 percent of agriculture is irrigated, under an optimistic scenario in which 80 percent of the gap between actual and obtainable irrigated yield is bridged, more than half of the additional food demand can be met by improving output per unit of water on existing irrigated land.

“With the technology and the tools today, we could potentially feed the world,” Raikes said. “But there is a barrier, and we’ve seen this barrier for many years in terms of delivering these technologies and tools to the people who need them the most. Again, I argue that we must pull on all levers and with an integrated and interdisciplinary approach.”

*“It will be your understanding of this crisis and your vision that leads to greater awareness and inspiring the necessary public and political will to support these investments.”*

That approach includes combining the best practices of today and those yet to be discovered. Today's best practices include: the right underlying seed technology, effective distribution and market access; great soil management, including appropriate fertilizer and practices like intercropping and conservation tillage; efficient irrigation; watershed management that brings communities together to think holistically about their shared watershed; and education and training so that information reaches farmers.

### Best Practices of Tomorrow

The Gates Foundation supports agricultural research and development, from the most basic to the advanced, that will lead to tomorrow's best practices, including efforts to help smallholder farmers develop and distribute more productive crop varieties that thrive in different soil types and are resistant to disease, pests and drought. Another major priority is the development of affordable water storage, pumps and micro-irrigation technologies. More effective and inexpensive technologies that let smallholder farmers capture and use water efficiently without creating unsustainable demands on natural resources remain critical.

Policies also must be devised to encourage more crop per drop, Raikes said. He outlined three characteristics of effective policies. First, policies must target the livelihood gains of smallholder farmers by securing water access through water

rights and investments in storage and delivery infrastructure where needed, and by investing in roads and markets. Second, policies must be integrated. Instead of focusing narrowly on rivers and groundwater, rain must be viewed as the ultimate source of water that can be managed. Instead of isolating agriculture as a production system, it must be viewed as an integrated, multiple-use system and as an agroecosystem, providing services and interacting with other agroecosystems. And finally, policies must provide the right incentives to support adequate water availability for producers. For example, rather than charging farmers for more water use, the parts of societies benefiting from reallocations may need to compensate farmers for less water use in agriculture.

#### **Water for Food: A Call to Action**

Raikes proposed an agenda for the Water for Food Institute to achieve “more crop per drop.” It includes: pushing everyone in the value chain toward more efficient use and toward greater awareness that water is a precious resource; employing innovations, such as using trade to promote the most efficient use of water; tapping science and technology to develop crops that more effectively use water; engineering ways to better capture and store rainfall; and encouraging better farm management practices so that available water is effectively and efficiently used.

“I feel that we must invest in and pull on all the key levers,” Raikes concluded. “We must take an interdisciplinary and integrated approach. It will be your understanding of this crisis and your vision that leads to greater awareness

and inspiring the necessary public and political will to support these investments. It’s going to require, through leadership and innovations, your collaboration and teamwork across disciplines and across geographies. It can be this global Water For Food Institute that brings leadership together to set and drive this integrated agenda for more crop per drop.”



Richard Nyberg/USAID

Watering plants by hand

# President's Welcome

## A Visionary Gift for the 21st Century

### James B. Milliken

President, University of Nebraska

The Robert B. Daugherty Charitable Foundation's \$50 million gift to the University of Nebraska to develop the Water for Food Institute is a visionary gift that began with a visionary man, James B. Milliken said. Robert Daugherty returned to his home state of Nebraska after World War II to found the world's most successful irrigation company. In his ongoing commitment to water use efficiency, he was a leader in the critical challenges facing agriculture.

Nebraska may seem an unlikely place to tackle those challenges with a new Water for Food Institute, Milliken said, but the state has a long history of serious, bold people who have helped change the world. Warren Buffett, one of the world's wealthiest and most philanthropic people, has created enormous wealth for many, which has benefited not only the University of Nebraska, Buffett's alma mater, but many other institutions. The Omahan has not had to stray far from home to be an important financial figure.

Other Nebraskans have revolutionized agriculture, saving millions of lives and improving millions more. George Beadle, born in Wahoo, Neb., and a University of Nebraska–Lincoln graduate, made significant contributions in molecular, cellular and developmental biology, earning a 1958 Nobel Prize with Edward Tatum for the “one-gene, one-enzyme” theory. Beadle's contemporary, Henry Beachell, also a Nebraska native and UNL alumnus, worked in the U.S. Department of Agriculture's rice breeding program. Later, at the International Rice



James B. Milliken

Research Institute, he developed rice strains that dramatically increased yields, saving millions of lives. He won the 1996 World Food Prize and, working into his 90s, established a genetic seed bank for rice.

Norman Borlaug, an Iowan who attended the University of Minnesota, worked in Mexico in the 1940s and 1950s, breeding new disease-resistant wheat varieties. His work led to a sixfold increase in yields. In the 1960s, he convinced Pakistan and India of the value of wheat and is credited with saving millions from famine. Borlaug's work played a leading role in the Green Revolution, for which he won the 1970 Nobel Peace Prize.

The next Green Revolution must be greener than the first, Milliken said, citing Bill Gates, who has called for considering small farmers' needs, exploring a wide range of techniques, adopting solutions to local circumstances and ensuring sustainability.

“Doubling food production in a way that supports all human life and protects our environment is a challenge that will help define the work of the new Water for Food Institute,” Milliken said. “We envision it as a distributed global entity, with Nebraska as its home and the site of what we hope will be the most significant conference in the world on water for agriculture, but with research fellows, partners and collaboration centers located throughout the world.”

The global Water for Food Institute is a research, education and policy institute committed to helping the world efficiently use its limited fresh water resources to ensure the food supply for current and future generations.



The institute hopes to attract outstanding leadership from top research and teaching talent, and to build on the University of Nebraska’s more than 100 faculty members from disciplines related to water and agriculture, who include internationally respected leaders in surface water and groundwater interactions, drought mitigation, and water law and policy. Eventually, the institute will be located on Nebraska Innovation Campus, a 249-acre private-public development focused on food, fuel and water.

“In making his gift to the university, Bob Daugherty said that we have the right people and the right place at the right time to be successful,” Milliken said. “I’m grateful for his confidence,

and I share his belief that Nebraska, with its richly varied water resources, its national leadership in agricultural production and irrigation and its public university that has a rich history of research and education and outreach on water, is indeed the right place.”

Beadle, Beachell and Borlaug accomplished tremendous agricultural

The goal of the institute’s research will be to inform wise policy, effective management and public understanding. Planned initiatives include cooperative research projects, interdisciplinary academic degrees and certificates, international research fellows and visiting scholars, a Water for Food academic journal and a global clearinghouse for information.

advances using the best science available at the time. Today’s technologies and global communication provide great optimism that much more can be achieved in the 21st century, Milliken said.

# Chancellor's Welcome

## Water for Food: Imagining the Future

### Harvey Perlman

Chancellor, University of Nebraska–Lincoln



Harvey Perlman

The Robert B. Daugherty Foundation's gift of \$50 million to establish the Water for Food Institute, one of the largest gifts in University of Nebraska history, could not be more timely or important, Harvey Perlman said. The institute will allow the university to leverage its strengths and long-time expertise in research, policy analysis and education in water and agriculture to solve a critical world problem.

Efforts to advance food production are not always universally acclaimed, Perlman said. Floyd E. Dominy, who was born on a Nebraska farm 100 years ago and recently passed away, provides one example. While working as an extension agent in Wyoming, Dominy realized that building small dams to store water would help farmers in his region. He built more than 300 dams, more than previously built in the entire West. Later, as commissioner for the U.S. Bureau of Reclamation, he presided over the construction of many

prominent dams, including Glen Canyon and Flaming Gorge. Dams were applauded for generating power, creating lakes, providing water for growing crops and expanding urban areas. But they also were denounced for destroying Native American historical sites, ecosystems and fish habitats. "Dominy's activities on behalf of water for food remain clearly controversial, and illustrate the inevitable tradeoffs and competing demands made of our water resources," Perlman said.

The University of Nebraska, a longtime leader in research, education and outreach in water, agriculture and natural resources management, offers the expertise and knowledge base to assume a leadership position. Its expertise extends beyond producing technologies and innovative management practices to sociology, economics, computer science, law and engineering – all important to addressing these complex issues.

The university has doubled its research funding in the past decade, enabling the leadership to begin developing Nebraska Innovation Campus, a premier private-public sector sustainable research campus on 249 acres adjacent to the university. The campus will provide exciting opportunities for collaborative research and product commercialization. Building on the university's strengths, the campus will focus on water, food and fuel. The Water for Food Institute will play an important role, sharing many goals of developing sustainable solutions

through partnerships with private enterprise and with researchers and educators throughout the world.

“The Water for Food Institute strengthens our university in ways we have yet to imagine and to build networks with partners we have yet to

meet,” Perlman concluded. “Your attendance at this conference is just the beginning and gives us great optimism that we have focused our vision on the right strategies to create a preferred future. We are open and look forward to engaging in partnerships with many of you in this room to address the critical issues that bring us together.”



Nebraska Innovation Campus

## Speakers

### Increasing the Drought Tolerance of Crops: Urgency, Myths, Achievements and Realities

#### Gary Atlin

Associate Director, Global Maize Program, International Maize and Wheat Improvement Center (CIMMYT)

Breeding programs in Africa and Asia that screen for drought tolerance are effective and important components in improving food security, but few breeding programs do it, Gary Atlin said. He described the successful drought-tolerant breeding programs of the International Maize and Wheat Improvement Center (CIMMYT) and the International Rice Research Institute (IRRI).

Extreme rural poverty persists in rainfed systems and is concentrated in two major areas: maize areas of eastern and southern Africa and rice-based systems in South Asia. However, inexpensive grain from rainfed systems also keeps prices low, helping the urban poor survive, Atlin said.

Unlike commercial farmers, subsistence farmers must worry about yield in drought years because their food security and capital stock depend on what may be the difference between a half-ton yield and a quarter-ton yield.

#### Managed-stress Breeding

Atlin first looked at the origin of yield gains in rainfed agriculture in North America. In Iowa, rainfed corn yields in the 1920s were comparable to today's yields in Africa. A substantial jump occurred mid-century with continued gains since then because plant breeding increased biomass and tolerance to high plant densities, improved



Gary Atlin

drought tolerance and nutrient recovery, and faster recovery from cold stress.

These gains were achieved almost entirely from wide-scale, multiple-location testing under rainfed conditions in the targeted population of environments. Is that model applicable to rainfed systems in Africa and Asia? Atlin asked.

The approach is prohibitively expensive because of the need to test at hundreds of locations and so cannot be precisely reproduced, but expanding rainfed testing in Africa and Asia is greatly needed. Breeding programs and private companies, however, are investing more in yield testing under managed stress for tolerance to low fertility and drought conditions. CIMMYT was an early pioneer in breeding for drought tolerance in maize.

A managed-stress screen must be integrated into the breeding program, as opposed to using it only as a genetic analysis or research tool. CIMMYT screens for both low fertility and drought tolerance under severe stress conditions to identify materials with drought tolerance, a significant difference from commercial corn breeding in the U.S. CIMMYT aims to reduce yield 60 to 80 percent in its screening process and looks for high genetic correlation with what's happening in farmers' fields under the worst conditions. Working in the rain-free season, irrigation is stopped about 30 days before flowering with the hope of detecting severe stress symptoms. "It's actually a tough target to hit precisely," Atlin said.

"It's an art, not a science, generating these screening environments." The results can be dramatic-looking differences in plant water status and sometimes in yield, even when plant water status differences are invisible because of differing sensitivities of the flowering process.

### 30 Years of Recurrent Selection

Using this protocol, CIMMYT has conducted recurrent selection programs for 30 years, making gains of about 100 kilograms per hectare per selection cycle every couple of years. Grain yield increases appear to be associated with reduced ear and kernel abortion, shorter anthesis-silking interval and a faster growth rate at the ear shoot around flowering. Although additional

harvest index improvement is often viewed as unable to further increase water productivity, that is not the case in drought-prone environments, Atlin said. Stress also severely affects harvest index in rice and maize and is a major area of gain when managed-stress screens are incorporated into the product development pipeline.

*"We're very concerned that the new tools that are becoming available be applied in breeding programs targeted at the poorest farmers in rainfed situations."*

Atlin described CIMMYT's Stage I testcross evaluation of four to six environments, including optimal rainfed management, severely nitrogen-depleted conditions, and managed stress in the dry season. CIMMYT has just begun experiments to examine

gain from selection in its modern Africa-based programs. IRRI also incorporated drought screening into its rice breeding program in India and found, surprisingly, that the workhorse Green Revolution-irrigated varieties were much more sensitive to drought and were failing regularly under severe stress conditions. IRRI identified materials that are yielding about a ton more under stress conditions, and several varieties have been released.

"Gains from rice and maize breeding programs have been quite large once we actually started to incorporate directed stress treatments," Atlin concluded of CIMMYT and IRRI's experiences. This first step resulted in a 20 percent yield increase relative to the commercial materials in southern and eastern Africa; one breeding cycle in rice delivered 50 percent gains under severe stress. Although this rate of gain won't continue,

## Speakers

Atlin said, it is unlikely that transgenes or quantitative trait loci would have delivered similar gains without breeding advancements. The new biotechnology tools are adding onto a solid foundation of cultivar development.

“We’re very concerned that the new tools that are becoming available be applied in breeding programs targeted at the poorest farmers in rainfed situations,” Atlin said. CIMMYT is sourcing and applying tools, such as improved screening approaches and phenotyping protocols, double-haploid inducers, molecular-marker technologies and breeding informatics management.

### Transgenic Future

CIMMYT also is involved in public-private partnerships to develop transgenes for improving drought tolerance and nitrogen-use efficiency for African smallholders through the Water-Efficient Maize for Africa project with Monsanto Company and the Improved Maize for African Soils project with Pioneer. The products of these collaborations will be drought-tolerant and improved nitrogen-use transgenic varieties available to African smallholders under humanitarian licensing and market segmentation arrangements.

Deployment of transgenics in developing countries requires \$25 million to \$100 million and at least 12 years to make it to a farmer’s field, Atlin said. Few African countries have a regulatory framework allowing them to accept transgenic technology, and those that do rely on data from the U.S. regulatory system. “At the moment, and I believe for the foreseeable future, only transgenes that can be commercialized by a

company for farmers in a developed country will be made available in developing countries.” A transgene beneficial in Africa, but detrimental to U.S. yields, most likely will not be developed for marketing.

Drought tolerance in maize appears to be affected by many genetic factors, for which marker-index selection approaches are more suited. Fortunately, reduced costs for genotyping technologies are starting to allow CIMMYT and small breeding programs to apply these technologies. Next-generation sequencing of genome representations will make the haplotype, rather than the line, the selection unit, which will allow programs to share information but not germplasm. That ability, along with other advances Atlin described, will encourage the development of “open-source” breeding, which could reduce breeding cycle times by fivefold and potentially double genetic gains.

Making breeding informatics accessible to smaller breeding programs will be critical to the success of the new breeding system. “There’s a wave of genotypic data that’s going to break over us in the next year or so,” Atlin said. “This is not the distant future. This is happening. We will have thousands of polymorphisms available to use in making selections within the next year to 18 months. We need to put the systems in place to allow us to surf this wave of information.”

### Constraints

Logistical constraints remain. Seed is expensive and difficult to produce, and many small companies in Africa cannot produce needed quantities, creating a serious logistical problem getting hybrid seeds to farmers. CIMMYT



Inspecting drought-tolerant maize in Tanzania

works with 14 African countries and has released more than 40 varieties. Since 2003, collaborating seed companies have produced seed for more than 3 million hectares, but 30 million to 40 million more African farmers, as well as farmers in Asia and Latin America, need these seed gains.

“Breeding for drought tolerance is both urgent and effective, but relatively few breeding programs in the developing world actually do it,” Atlin said. Delivering drought tolerance requires an integrated pipeline with clearly defined target environments, expensive and intensive new phenotyping tools and extensive multi-location rainfed testing systems in the target environment.

Accomplishing it will take public consortia, public-private partnerships and open-source breeding models.

“There is going to be a revolution in breeding methods based on low-cost, high-density genotyping in the next three years,” Atlin concluded. “It’s already happened in the private sector. It’s going to happen now in the public sector. We need to make sure that farmers in drought-prone environments, the poorest farmers in rainfed regions of the world, are among the first to benefit.”

## Speakers

### Charting Our Water Future: Economic Frameworks to Inform Decision-Making

#### Giulio Boccaletti

Expert Associate Principal, McKinsey & Company

According to *Charting our Water Future*, a McKinsey & Company report, the world faces a significant water challenge and business-as-usual practices will not suffice, Giulio Boccaletti said.



Giulio Boccaletti

Cost-effective, sustainable solutions are possible but will require engaging economic activities across entire societies. The report, commissioned by concerned private-sector enterprises potentially affected by water scarcity, provides a useful decision-making tool for tackling water issues.

#### The Water Challenge

Currently, the world uses 4,500 billion cubic meters of water annually to meet agricultural, industrial and municipal demands. By 2030, under a business-as-usual scenario, the world would require nearly 7,000 billion cubic meters. However, according to estimates in the report,

only 4,200 billion cubic meters of water will be available in 2030 for human uses, a measure not just of physical scarcity, but of the ability to sustainably supply water when and where it is needed. The figure is calculated by subtracting environmental needs, transfer loss and other loss variables from total renewable water resources for important global water basins.

Those figures represent a global projected water gap of 40 percent between future demands and capacity, with some areas facing gaps of up to 75 percent, Boccaletti said. The growth in demand stems largely from agriculture but also from industry and municipal systems.

How can this gap be closed? Boccaletti asked. Will countries be able to increase supply, or will they need to reduce demand either by increasing efficiency or by curbing economic activity? The problem is global, but ultimately solutions must occur at a local level. China's water gap, for example, will be driven primarily by agriculture but also by significant growth from industrial and municipal uses, particularly thermal power production. "Power production is a significant fraction of the water demand in China," Boccaletti said.

In South Africa, roughly 60 percent of water use goes to irrigated agriculture (20 percent of the country's agriculture is irrigated), but a growing

demand comes from mining and other industrial uses. “The reality is that the competition between water for food and water for energy and water for other industrial activities is one of the fundamental issues that South Africa is facing,”

Boccaletti said. India faces an even larger water gap across most sectors, driven by water demands from rice, wheat and sugar production.

#### **Need for Action**

Some have questioned whether a crisis is looming. In the past, increases in supply and improvements in water productivity have averted predicted imminent crises. Can the gap be closed by adding supply, such as building a new reservoir, to deliver more water where and when it is needed? Adjusting for historic rates of increasing supply and decreasing demand reveals that 60 percent of the 40 percent projected gap remains.

India illustrates why supply may be constrained. Reviewing costs of various supply measures used today, such as small-scale irrigation infrastructure and rainwater harvesting, the average cost of supply is about 2 cents to 3 cents per cubic meter. The average cost of adding new supply is higher, about 7 cents per cubic meter, and the cost of marginal units of water that can be delivered is closer to a dollar per cubic meter. China, too, illustrates another supply constraint. The relative fraction of non-usable water is increasing because of pollution, so water quality is becoming intertwined with quantity.

#### **Solutions**

If past solutions cannot close the 40 percent water gap, then what can be done? To answer that question, the report includes an introduction to the water-availability cost curve, which

takes into account all water uses, from drip irrigation to improved crops and efficient shower heads, and determines their specific costs and potential to close the gap between supply and demand in a particular basin. Overlaying the cost curve onto the gap helps determine which measures can close the gap and how far up the cost curve it is necessary

to go. “It offers a menu of options, essentially, and a quantification of their potential and their cost,” Boccaletti said.

Using this method, can India or China, for example, close its water gap? What will it cost, and what would it take? No silver bullet exists; each country requires different solutions. India, for example, will need 755,800 million cubic meters of water by 2030. The cost-curve analysis shows that India has ample opportunity, in theory, to solve its water crisis. The cost to close the gap would equal \$6 billion per annum, a small figure compared to India’s \$50 billion, five-year agricultural program. About 80 percent of the ability to accomplish this involves increasing agricultural efficiency, including no-till farming and increased fertilizer use. “In the case of India, the most cost-effective measures have to do primarily with the rehabilitation of the existing infrastructure,” Boccaletti said.

*“The cost-curve analysis actually starts framing the choices that policymakers have in thinking about the issue.”*

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China, in contrast, uses agricultural water more efficiently, but many opportunities exist to increase industrial and municipal efficiency. So China, too, can close its water gap, while, surprisingly, also saving \$30 billion per year. Measures include industrial efficiency, such as reusing water in steel production.

The tool can be used to compare costs and savings using combinations of solutions and scenarios, such as increasing climate change effects and accelerated economic growth. This analysis demonstrates that closing the water gap is possible. In fact, the problem is not a lack of technology or money; it's a policy, incentive and institutional question, Boccaletti said. "This actually starts framing the choices that policymakers have in thinking about the issue."

### Transformation Pathway

Boccaletti outlined six elements to drive water sector transformation: accepted, fact-based vision to drive change, not anecdotal evidence; leadership and institutional alignment; correct regulatory schemes and incentive design; private-sector investment because many countries are still fiscally constrained; the role of large-user efficiency; and technology development.

If the issue is not technology or money, then why are changes not happening? Boccaletti asked. Numerous financial, political, structural and social barriers exist, from insufficient access to capital and pricing distortions due to subsidies to limited management capacity and lack of information.

The cost curve does not provide solutions to all these barriers, but it does provide a menu with which to analyze various options based on how difficult or easy they may be to implement. McKinsey and the report's company sponsors are engaging with governments to use these and other analytical tools to address the water-reform agenda. "I think it's particularly interesting and timely that an institution that worries about water for food starts thinking about, at a global level, how we can transition to a blue economy and to a sustainable use of our water resources," Boccaletti concluded.

## Water Security: What is the Challenge and What Needs to be Done?

### John Briscoe

Gordon McKay Professor of the Practice of  
Environmental Engineering, Harvard University

Strong public leadership partnered with the private sector is providing innovative water resource management models in the financial, institutional and technological sectors, John Briscoe said.

Understanding the historical, social and cultural contexts in which water exists is essential to conducting the practical work of watering the world. The Mandarin symbol for political order, for example, is a combination of the anagrams for river and embankment or dike, illustrating the ancient importance of water in China. To control water is to impose social order. China's Three Gorges Dam, then, is as much about political symbolism as flood protection and hydropower.

Historical context also suggests the provisional nature of water management. Solutions appropriate at one time often lead to new realities. "The first point I'd like to make," Briscoe cautioned, "is the great danger of looking back and saying how stupid we were in what we did, when things that were done at that time might have been entirely appropriate for that particular context, but then gave rise to a new set of challenges."

Briscoe looked to Pakistan to illustrate the importance of history and evolving context when dealing with practical concerns.



John Briscoe

Nearly all of Pakistan's water comes from neighboring countries. When Britain drew the boundary between Pakistan and India in 1947, 85 percent of the irrigated area of the Indus Basin was in Pakistan, while the headwaters feeding it remained in India.

After 10 years of negotiations, a solution was devised giving Pakistan and India each three rivers feeding the Indus Basin. Both countries built an infrastructure of dams and canals to link their designated water to irrigated land within their boundaries. "This has been, I think, one of the great achievements in the world in the last 50 years," Briscoe said. "Something worked between two countries that have often had a variety of great pressures between them for almost 60 years."

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Everything is provisional, however, he reminded. India is undertaking – rightfully, Briscoe believes – a large hydroelectric development program that puts stress on the Indus Waters Treaty. Will the treaty’s past success evolve to face new realities? Such water tensions are not unique. Worldwide, 260 river basins are shared by two or more nations, and tensions are growing between and within countries.

### Endogenous Tools

In many areas, old tools are still important to solving current water problems. The U.S. has 6,000 cubic meters of water storage capacity for each resident, compared to Pakistan and India with 150 cubic meters, and, at the extreme end, Ethiopia with just 40 cubic meters per resident. In Ethiopia, rainfall and the gross domestic product are nearly perfectly correlated. “If nature fails, the country fails,” Briscoe said. “This is the simple reality of living without any hydraulic infrastructure.”

Countries have small endowments to invest in infrastructure. India, for example, developed the Bhakra-Beas complex, a project now widely criticized as primarily benefiting large landowners. However, Briscoe countered, “creation of agricultural wealth is not something which stops with the farmers. It then requires a whole set of forward and backward linkages to process the food, to produce the inputs for this.” An analysis found that indirect benefits equaled direct benefits. The biggest beneficiaries were people without land because of the increased demand for labor and higher wages. “This sort of investment really provides a foundation for a very broad amount of social and economic development,” Briscoe said.

Financial investments have changed considerably in the past decade. The World Bank and regional development banks once financed infrastructure projects, such as dams. In the 1990s, controversy



International Rice Research Institute [www.irri.org](http://www.irri.org)

Varieties of rice grains

from nongovernmental organization (NGO) protests against water projects persuaded international financial institutions to largely stop financing dam projects. As a result, middle-income countries like Brazil opted to continue building infrastructure on their own, while poorer countries that needed financial support were left in desperate situations.

In the last decade, China has moved into the developing world, financing 215 dams outside of China, compared to the World Bank's five. This shift is viewed unfavorably in the West, but developing countries welcome Chinese dams and construction, Briscoe said.

#### **Innovative Models**

New ways of structuring institutions offer innovative models in water resource management. The Manila

Water Concession, which provides water to about 50 million people through a locally led concessionaire, is a successful example. The project, led by former Philippines President Fidel Ramos, now provides water to Manila residents, 30 percent of whom previously had no formal water supply. Briscoe also described as institutional models SABESP, a Brazilian water utility; a Chilean "water stamp" program; and a Brazilian "condominial sewage" system.

Model public-private partnerships also are occurring in irrigation and drainage. For example, in Brazil most irrigation is private, provided by individual farmers. In the semi-arid northeast, however, Brazil is trying to increase output of the São Francisco River through public-private

irrigation projects in which private "anchor enterprises" provide technology, marketing and credit, while the state provides millions of dollars in equity. The concessionaires must make 30 percent of the area available to small farmers. "I think this sort of innovation is what's needed if small farmers are going to be able to reap the benefits of this increasingly complex and information-rich area," Briscoe said.

Water for energy also is integrally related. Rich countries have developed around 80 percent of their hydroelectric potential, while Africa has developed just 3 percent, suggesting huge

potential. New hydroelectric projects that use bulb turbine technology, such as those in Brazil's Amazon, submerge 100 times less area per megawatt generated than previous technology.

Historically, these projects were financed publicly. In Brazil, a regulator now arbitrates among developers, users and the government, providing a framework for competition that has resulted in a 30 percent reduction in project costs.

Exciting things are happening in managing these water resource sectors, Briscoe said. The Australians have established a sophisticated system of tradable water rights, where sellers make more from selling water when the price is high and water is scarce than from growing low-value crops, resulting in water moving from low-value to high-value uses. The Australian Treasury found that intra- and interstate water trading lowers by two-thirds the economic cost of reduced water availability on gross regional product.

*"We're going to need public leadership and private innovation."*

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### Investment in Agricultural Innovation

Technologies offer a third area of innovation. Agricultural technical assistance has suffered the same fate as infrastructure investment, down to 3 percent in 2005 from 18 percent in 1980. Brazil, in contrast, continued to invest in agricultural research, resulting in enormous returns. Agricultural output is now three times higher than 25 years ago, not from cutting down the Amazon Forest, but due to innovation and better use of resources. “If you ... contrast a Brazil with an Africa, which depends on the whims of donors, the contrast, in my view, couldn’t be more striking,” Briscoe said.

Nevertheless, the development community, as articulated in the World Bank’s International Assessment of Agricultural Knowledge, Science and Technology for Development, eulogized small-scale and organic farming and denounced the Brazilian model of technology-intensive and large-scale agriculture that relies on genetically modified organisms (GMOs), Briscoe said.

Yet middle-income countries understand that GMOs are essential to increasing agricultural production, Briscoe said, adding, “We then have, in my view, a really tragic situation. Because when you look at development, the middle-income countries have gone their own way very successfully. And Africa stays out of GMOs, as I understand, largely because of pressure of European donors. ... This is, to me, a sin.”

Briscoe described other technological innovations in water and wastewater treatment technologies, nanotechnologies, desalination and information technology.

### Private Sector Engagement

New forms of partnerships also offer exciting new processes. Companies that see water scarcity and pollution as threats respond in one of three ways: by partnering with an NGO largely for appearances, by reducing their footprint to acceptable levels, or by adopting a philosophy of creating shared value. Nestlé, for example, believes that to improve business, it benefits the company to view itself as part of the long supply chain and to get involved in demanding that government better manage water resources.

A growing group of global companies is beginning to understand the world’s water challenge, to question what it will mean to their businesses and to engage with public policy, Briscoe said. He added that this positive participation must be populated by not only multinational corporations but also domestic companies of high moral standing that understand the local context.

“We’re going to need public leadership and private innovation,” Briscoe concluded. He believes universities serve an important role in training, in generating and convening knowledge, and in creating a new sense of partnerships in which mutual learning occurs. “The world has changed. The world doesn’t begin and end in the United States anymore. ... The world is out there in China, India, Africa, Brazil. These are places with enormous intellectual capability, where they’re able to actually innovate often much faster than we are.”

## Comparing Green Revolutions in Asia and Nebraska: Lessons for Sub-Saharan Africa

### Ken Cassman

Heuermann Professor of Agronomy and Director, Nebraska Center for Energy Sciences Research, University of Nebraska–Lincoln

Comparing the potential for an agricultural revolution in Africa with the 1960s Green Revolutions in Asia and Nebraska, Ken Cassman concluded that Africa could achieve its own by following those examples in which irrigation played a pivotal role.



Ken Cassman

### History of Irrigation

Human urban civilization began with irrigated agriculture. About 8,000 years ago, the fertile crescent of Mesopotamia and the Nile Valley underwent agricultural transitions. In Egypt, for example, the Nile River flooded yearly, covering the valley floor. When the water receded, farmers sowed their crops. They irrigated the arid land by lifting water from the water table, using tools such as the shadoof. Today, because of irrigated agriculture, Egypt has some of the world's highest yields. In Asia, rice could be grown in areas that flooded naturally; dikes and lifting water kept the soils flooded. Around the world, irrigated

agriculture transformed civilizations, supporting cultural diversity and productivity.

Yet by the mid-20th century, projections showed food production would not meet the growing population's needs. Per-capita grain production peaked in the 1980s and has been declining steadily since. Today, 1 billion people do not get enough nourishment.

### Irrigation Benefits

The need to improve food production propelled the Asian Green Revolution in the 1960s, underpinned by a massive expansion in irrigated area, which jumped from about 10 percent to about 18 percent of total crop-producing land. That 18 percent of irrigated land now produces 40 percent of the human food supply.

The high productivity of irrigated agriculture reduces the pressure to expand agriculture into environmentally sensitive areas. People already produce food in areas that should not be farmed, using unsustainable practices that degrade the land. In addition, urban expansion has reduced land area for grain crop production by about 1.8 million hectares annually since the mid-1980s. "If you want to accelerate climate change, if you want to threaten the existence of orangutans and Sumatran tigers, just start reducing the productivity of irrigated agriculture," Cassman said.

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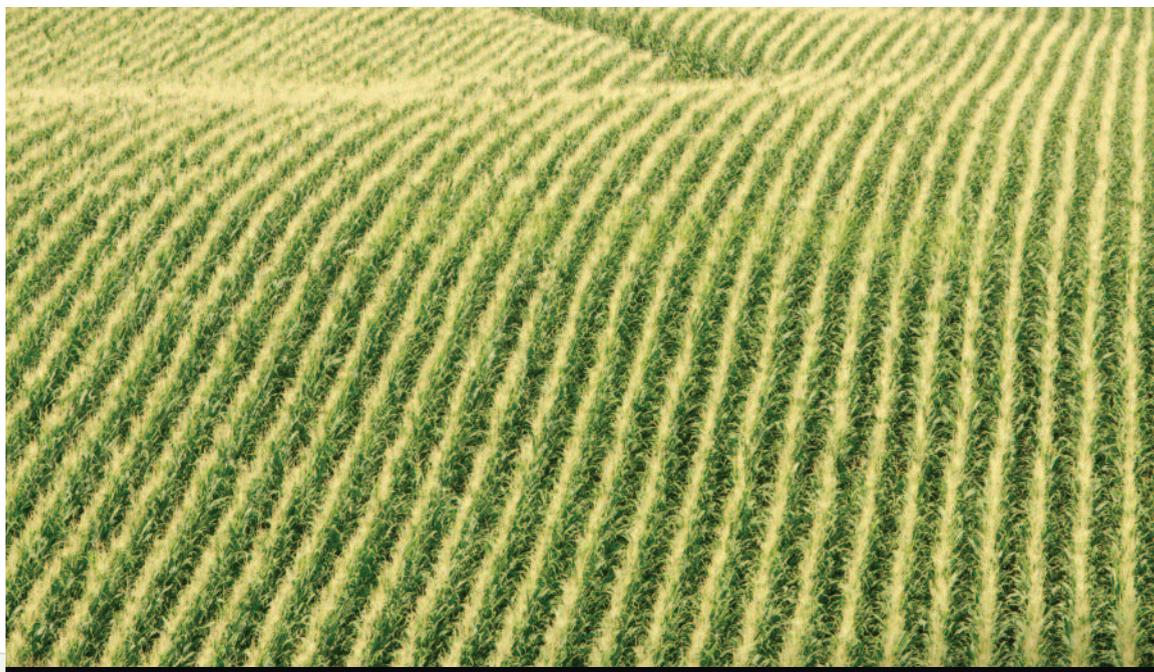
A stable human population will be achieved when the world average per capita income equals \$4,000, the point at which female fertility falls to replacement levels, he said. Will “business as usual” produce enough food at that point? Cassman asked.

To answer that question, Cassman compared the rate of gain for the world’s three major cereal crops of corn, rice and wheat, which comprise nearly 60 percent of human calories, either eaten directly or through livestock products. “With all the investment in science and technology in agriculture, with all of the increase in irrigation that’s occurred in the last 40 years,” he said, “it has allowed us to maintain only a constant rate of increase. The relative rate of gain is decreasing all the time.” Projections show the rate of yield gain required to meet future food demand is not even close, Cassman said.

### Asia’s Green Revolution

Asia’s Green Revolution began with new science and technology, most notably high-yield rice varieties that allowed farmers to grow two crops per year instead of one. That second crop required irrigation during the dry season, effectively doubling the amount of irrigated land. “The Green Revolution wouldn’t have happened in Asia without an expansion of irrigated area,” Cassman said.

Irrigated farming practices kept food production ahead of population growth, benefiting society beyond fulfilling nutritional needs. Because irrigated agriculture is predictable, farmers could purchase improvements, fueling small-scale entrepreneurial industries in inputs, equipment and foods. Higher production lowered the cost of food for both rural and urban poor, freeing income for other sectors of the economy.



Aerial view of cornfield

In addition, the higher value of irrigated agriculture justified government investment in education, research and infrastructure to support agriculture – benefits that also extended to rainfed agriculture.

### **Nebraska's Green Revolution**

Nebraska sits in an incredible location, Cassman said. Its western edge forms part of what was once known as the Great American Desert. The state's eastern half belongs to the Corn Belt, the world's most productive agroecological zone. The Rocky Mountains and the monsoonal moisture from the Gulf of Mexico create a moisture gradient across Nebraska from 14 inches of annual rainfall in the semi-arid west to about 31 inches in the eastern third. A greater climate gradient exists within Nebraska, Cassman said, than from the Atlantic Ocean to the state's eastern border.

The state's semi-arid central and western areas rely on irrigation, which accelerated during the 1960s, much as it did in Asia. Nebraska is now equal parts rainfed and irrigated agriculture and has more irrigated acres than any other state. Over time, Nebraska corn and soybean yields rose due to improved technologies. Because irrigated agriculture yields are consistent, deviations around the norm from year to year are small, even in the dry west. In eastern Nebraska, rainfed agriculture still does relatively well because of generally sufficient rainfall, but in the harsher west, rainfed agriculture experiences lower yields and greater variability year to year.

As in Asia, the stable supply of grain from irrigated agriculture has allowed other industries to invest. Nebraska slaughters more cattle than any other state – 7.6 million head – most of

them coming from surrounding states without irrigation. Irrigation also has allowed Nebraska to increase its rate of gain in ethanol production compared to other states. Today, the biofuel industry, which didn't exist 12 years ago, produces 1.8 billion gallons of fuel annually, worth \$3 billion a year, \$1.5 billion in capital investment and 1,000 jobs. Nebraska also is home to the world's largest pivot irrigation manufacturers.

Nebraska's population has increased 26 percent since 1960, to 1.78 million in 2008. However, the agricultural product per capita has increased fifteenfold during that period because of investment in irrigation and the value-added industries that irrigation enabled. Nebraska derives \$10,000 per capita from agriculture, more than any other state.

As in Asia, Nebraska's Green Revolution began with new science and technology, based largely on irrigated agriculture and integration with value-added industries. These advances also benefited rainfed agriculture. The rapid increase in yields and farm income lowered food prices for rural and urban poor. And the higher value of agriculture in Nebraska justified public sector investment in education, research, extension and infrastructure, as well as private sector investment in seed, equipment, processing and banks. The model for development in Nebraska was very similar to the model in Asia, Cassman said.

### **Africa's Green Revolution**

“What's the vision for irrigated agriculture in a Green Revolution for Africa?” he asked. “I've heard about irrigation, but I haven't heard if it has a significant role in ensuring the success of a Green Revolution in Africa.”

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Much of Sub-Saharan Africa has the water conditions and the ability to support crop yields similar to semi-arid western Nebraska. Although areas of Africa receive higher rainfall and are well watered, proximity to the equator and higher temperatures create much higher evaporation rates.

Although not as well watered as Asia nor as amenable to physical infrastructure such as flooded rice, Sub-Saharan Africa has significant water resources. In fact, Cassman declared, Africa has enough water to provide stable yields and income to support investment in associated industries and infrastructure, which would benefit rainfed agriculture as well.

“If their agriculture is much more like the harsher rainfed environments of the western Corn Belt, can rainfed agriculture do it alone?” he asked. Africans have to perceive agriculture as profitable and worth the investment. If in one in four years, there’s no profit, as happens in rainfed systems, the return on investment is reduced. Although Cassman agrees that massive investment in rainfed agriculture is needed, he believes irrigated agriculture must play a critical role in Africa’s Green Revolution – a role that is not yet well defined.

A vision for irrigated agriculture in Africa must include an understanding of the location, quantity and quality of the renewable water supply to achieve a sustainable balance with environmental services and biodiversity.

*“If Africa’s agriculture is much more like the harsher rainfed environments of the western Corn Belt, can rainfed agriculture do it alone?”*

Policies, infrastructure and markets also must enable irrigated agriculture. Nebraska’s Natural Resources Districts (NRDs), a unique system in which boundaries are based on a watershed unit of management, offers a model. Each of Nebraska’s 23 districts is autonomous and governed by a locally elected board of directors that has authority to tax land, implement policies, conserve resources and invest in enhancing resources. Each sets its own priorities and develops programs to serve local needs.

Many questions about irrigated agriculture in Sub-Saharan Africa must be answered before a sustainable agricultural industry will be possible, Cassman concluded. Water depletion, for example, will be a major challenge. Because Nebraska has dealt with similar issues in a similar environment, the state and a new institute can be valuable partners in the future water for food challenge.

## Science Challenges at the Water/Food Nexus: An NSF Perspective

### Richard Cuenca

Program Director for Hydrologic Sciences,  
National Science Foundation

Richard Cuenca discussed the predicted effects of climate change on food production, the need to offer farmers incentives to irrigate less to maximize profits, and water and food production research supported by the National Science Foundation (NSF).

### Climate Change

Climate change will undoubtedly affect future water resources, but discrepancies among current climate change models make predictions difficult. In a review of climate change models, fewer than two-thirds agreed about whether climate change in a region would increase or decrease precipitation, with disagreement across much of the globe in parts of North America, South America, Sub-Saharan Africa, the Indian sub-basin and Australia.

In comparing two models – those of Australia’s Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the National Center for Atmospheric Research (NCAR) – the NCAR model predicts wetter conditions in Sub-Saharan Africa, Australia, India and parts of South America, places where the CSIRO model predicts drier conditions.

“These models simply do not agree,” Cuenca said. “Obviously we still have a ways to go in trying to get the correct forecast for climate change predictions.” Using NCAR’s climate



Richard Cuenca

change model, along with hydrology and crop production models, the International Food Policy Research Institute predicted the climate-induced change in production of various crops in 2050. Although some regions made gains, the predicted global production declined for all crops.

The analysis predicts that irrigated and rainfed wheat would suffer the most significant losses at 42 percent and 28 percent, respectively, particularly in the Indian sub-continent; irrigated rice also would decline 27 percent; and rainfed rice and rainfed and irrigated maize would decline more modestly, but still lose 13 to 16 percent of global production.

By 2050, predicted climate change would not only lower available calories below levels that would have been achieved in a world without climate change, but also would drive them below

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2000 levels worldwide. Additionally, climate change would decrease any gains made in child malnutrition rates relative to no climate change. In Sub-Saharan Africa, child malnutrition rates would be predicted to increase even further by 2050.

### Deficit Irrigation Benefits

Deficit irrigation experiments demonstrate the need to irrigate less to maximize profit. Field experiments have shown that evapotranspiration rates, the combined water lost to soil evaporation and through plant leaf surfaces, are linearly related to applied water levels. Yield, however, is curvilinearly related to the amount of water applied. So while applying water at lower yields increases water productivity, at higher yields, much more water is needed to increase yields.



Irrigation water in Bangladesh

Cuenca cited a study demonstrating that, although maximum yield occurred at about 600 millimeters of water, after subtracting the cost of adding more water, the maximum net income occurred at about 500 millimeters of water.

“Why would a grower aim for maximum production when that last increment of water is going to have such a small effect on yield?” Cuenca

asked. “There must be some other, more beneficial use of these higher increments of applied water,” such as for habitat, urban areas or irrigating other fields. Though additional time and money should deter growers from irrigating to maximize yields, they do so to minimize risk, Cuenca said. He emphasized the need not just to improve irrigation, but also to consider socioeconomic factors.

In irrigated systems, he said, “there’s always a cost of water. What this shows is that to maximize the net income in this case, we should be operating at some point below the maximum yield.” What incentives could encourage growers to consider other objectives besides maximum production? Cuenca asked.

### NSF Investments

Cuenca described several national and international projects supported by NSF.

- The Long-Term Ecological Research (LTER) network, a cross-directorate research effort, addresses primary production, biodiversity, organic matter processing, disturbance regimes, and nutrient cycling and availability. The program began in 1980 and now spans 26 sites. LTER has become increasingly diverse and includes urban and international sites.

The program enables researchers to examine effects of climate variability and change, biogeochemical cycles, and biotic structure and dynamics. The data integrate ecology, geosciences and the social sciences and are available online. An educational component engages K-12, undergraduate and graduate students.

- A new \$40 million investment in climate modeling aims to elucidate the differences in climate simulation models. Some projects should address how to downscale general circulation models to regional and decadal scales to provide more practical information for irrigation managers and water resource managers.

- Water Sustainability and Climate, another new solicitation supported with \$25 million, requires an interdisciplinary approach incorporating biological sciences, earth sciences, social, behavioral and economic sciences, and engineering.

- The Office of International Science and Engineering supported an African Long-Term Research Network 2008 workshop in Mali to develop collaborative projects between U.S. and African scientists and to focus on nitrogen and phosphorus dynamics in different environments. Scientists will be working in eight villages of the Millennium Villages project to determine the nitrogen cycle and look for ways to find more nitrogen.

- The Mpala Research Centre ecohydrology project in northern Kenya evaluates the spatial and temporal patterns of plant water use efficiency from the individual plant level to landscapes. The site is part of the worldwide network of evaporative flux measurements and will provide information on evaporation,

transpiration and carbon fluxes. The project also investigates dryland ecosystem land degradation, which lowers the carrying capacity for cattle, reducing the nutrition available to the population. NSF supports the project because the global evaporative flux network contains few sites in Africa (and none in east Africa).

*“There’s always a cost of water. What this shows is that to maximize the net income in this case, we should be operating at some point below the maximum yield.”*

- The Basic Research to Enable Agricultural Development (BREAD) program, a partnership between NSF and the Bill & Melinda Gates Foundation, provides \$24 million from each foundation over five years to address constraints faced by smallholder farmers in the developing world. The program aims to identify the major

constraints in plant production and to find innovative ways to overcome them. “This is an exciting project for NSF,” Cuenca said. “Only through this project do we have the capability of supporting some of our foreign counterparts. We have lots of projects all over the world, worth millions of dollars, but we cannot support foreign investigators directly except through this BREAD program.”

Cuenca concluded by emphasizing the human dimensions of research. “Ultimately the reason we are here is because we want to make things better for these kids, and we want to see them not be in a position of malnutrition.”

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### A System Approach to Water Productivity

#### Robert T. Fraley

Executive Vice President and Chief Technology Officer, Monsanto Company

Although many people still have a pastoral view of agriculture, unprecedented modern technologies will meet the growing demand for food, Robert T. Fraley said. He described important advances in agronomic practices, breeding and biotechnology research occurring today in U.S. corn production.

Monsanto Company has committed itself to achieving sustainable agriculture and serving growers. Part of that commitment includes helping farmers double yields in corn, cotton, soybeans and spring-planted canola by 2030 – and do so with one-third fewer inputs per unit of output.

For U.S. corn, Monsanto's goal is to raise yields from today's 137 bushels per acre to 300 bushels per acre by 2030. Such gains won't be accomplished with a simple technique or method but through advances in biotechnology and breeding, as well as systemic improvements in agronomic techniques.

"It's important that this technology benefits all farmers," Fraley said, from large-scale U.S. growers to smallholder farmers across Africa and Asia. "We can see these tools improve their lives, their profitability and their cultures and societies."

In 1970, the year Fraley left his family's farm, his father was thrilled that corn yield averages hit 75 bushels per acre. Today, technology powers record yields – more than 160 bushels per acre. "In 2030, we'll look back at how we're growing corn today the same way we



Robert T. Fraley

kind of laugh when we look at how we did it in the 1970s. We're going to experience the greatest explosion in the advancement of agricultural technology that the world's ever seen," Fraley said.

If productivity gains continue along the historical trend line, average U.S. corn yields will reach 200 bushels by 2030. However, improvements in agronomic practices, such as fertilizer technologies and seed treatments, as well as advances in breeding using new genetic tools, will increase yearly baseline gains slightly. New biotechnology traits will drive gains even further to the goal of 300 bushels per acre.

Inputs are an important part of the equation. Since 1970, new technologies have resulted in the steady use of nitrogen and a dramatic reduction in pesticide use. Going forward, rainfall and chemicals will remain steady, and fertilizer use will rise slightly with increased yields. It's

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important, however, to consider increasing yields. The same bushel of corn in 2030 will be produced with one-third less water, fertilizer and pesticide than it is today.

Although Fraley centered his discussion on U.S. corn production, he added, “We will more than double yields in almost all the other world areas as a result of the advances of this technology.”

### **Agronomic Practices**

Advances in tillage techniques, planting, seed treatments and crop chemicals have changed agriculture dramatically, Fraley said. Conservation tillage, in particular, has been critical, helping to preserve soil quality and reduce water use and erosion. Conservation tillage has allowed crop production in parts of the world where tillage would release too much moisture to allow crops to grow. As additional reduced-tillage methods develop, planting and harvest technology and equipment improve, and genetics and traits advance, conservation tillage practices will continue to be adopted.

Monsanto’s Roundup Ready® technology has significantly improved in-crop weed control, facilitating the adoption of no-till and reduced tillage practices, Fraley said.

Planting technology also has advanced. In 1970, the average planting density in the U.S. was 17,000 plants per acre. Today, growers average 28,000. By 2030, Monsanto estimates that number will reach 35,000 to 40,000 plants per acre, driven by improved genetics and trait packages. Opportunities exist to greatly improve yield productivity. Breeding programs routinely plant 50,000 plants per

acre, and some reach as high as 70,000 plants per acre.

As plants are grown more compactly, the need for disease control becomes more crucial. Monsanto has done much work on multiple seed treatment coatings in which molecules interact effectively and synergistically, minimizing seed damage and maximizing yield. Fraley anticipates dramatic changes in seed treatment and crop disease management as new active ingredients become available. Monsanto’s Acceleron® seed treatment has seen dramatic results in early growth advantages, and its Headline® fungicide typically provides a 7- to 9-bushel increase in corn yield.

“Clearly, where this is going is bringing it together in an integrated fashion,” Fraley said. “And that is having exactly the right hybrid, targeted at the right population, with the right row configuration, with the healthy start, the optimal fertilization to drive yield. ... That’s where we’ll see a big opportunity for economic yield for farmers going forward.”

### **Plant Breeding**

Breeding advances in the last five years have been remarkable, Fraley said. New tools and the ability to breed and mine germplasm globally make it possible to insert only those genes that enhance U.S. corn performance. Advances in sequencing technology will allow hybrids to be constructed literally gene by gene to determine ideal combinations.

New sequencing technology requires advances in automation to speed the breeding process. Monsanto developed an automated seed chipper,

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a robot that precisely shaves off the endosperm, allowing DNA sampling. “That gives us the possibility of finding one rare recombination or trait event within millions and millions and sometimes trillions and trillions of events,” Fraley said.

The gains have been prolific. For example, Monsanto found that its DEKALB® brand hybrids improve gains in both drought and normal conditions. The fundamental seed genetics have changed dramatically in the past decade. “We’re taking the knowledge of the genetics and, increasingly, with our understanding of the structure and performance of individual genes, we will be able to target that performance under a given soil type, under a given weather condition and again maximize yield and productivity,” Fraley said.

*“We’re going to experience the greatest explosion in the advancement of agricultural technology that the world’s ever seen.”*

### Biotechnology

Fraley started Monsanto’s biotechnology program in 1980 when sequencing a gene was a six-month, multibillion-dollar investment. Today, the entire corn genome can be sequenced within a few weeks for a few thousand dollars.

Biotechnology has been adopted in 25 countries, with China and India leading the way. “That shows you how important, I think, the technology is, because in the end ... once that advantage is incorporated in the seed, every farmer in the world knows what to do with that seed and can capture that advantage with very, very minimal barriers to adoption, other than policy, for all practical purposes,” Fraley said.

The advent of Roundup Ready® technology for weed control and YieldGard® technology for corn borer and rootworm resulted in tremendous benefits for drought mitigation. Protecting roots and stems is the first step toward building a drought-protected platform. Therefore, even a basic drought product must be packaged with the best agronomics in insect and weed controls.

Several years ago, Monsanto had a tremendous breakthrough when a single transgene introduced into a plant showed dramatic drought tolerance. Monsanto is now testing that gene – from a bacterium – in corn and has found that it increases yield under drought conditions by about 11 to 20 percent compared to non-transgenic hybrids. The company expects to launch the first biotech drought-tolerant corn, Csp Drought 1, in the U.S. within a few years.

After that, Monsanto plans to launch the second-generation drought corn product, which will provide an advantage in areas where drought occurs intermittently. An independently acting drought gene that can weather the occasional drought adds insurance value. Fraley predicted by 2030, corn seeds with multiple drought and nitrogen-use genes will be available, each driving for incremental performance and yield.

### Global Expansion

The technology has quickly spread globally. The first biotech crop was launched in the U.S. in 1996 and today is grown in 25 countries. It should reach 50 countries by 2030, Fraley said.



Mature corn

“Clearly, the area that needs this technology the most is Africa,” he said. “I believe that there’s both the opportunity and the need to bring technology that can have tremendous benefit there.” The challenges are more complex than agriculture and technology can solve; it will require policy and infrastructure. “But I also believe at the very core, if we can bring in technology that increases yield, that increases profitability, that increases base food security, that it can improve lives.”

Monsanto has partnered with the International Maize and Wheat Improvement Center (CIMMYT) and several African institutions to bring biotechnology to Africa in an effort funded by the Bill & Melinda Gates Foundation.

The goal of the full-systems approach is to bring targeted genetics and hybrids to Africa, including drought- and insect-control traits. To date, results of drought-protected corn have been comparable to results in the U.S., Fraley said. “Our goal is literally within five or six years of the launch of this technology in the U.S. that we will be able to bring this technology into Africa,” he concluded.

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### ICIWaRM – America’s First UNESCO Category 2 Water Center

#### William S. (Will) Logan

Deputy Director, International Center for Integrated Water Resources Management (ICIWaRM)

The International Center for Integrated Water Resources Management (ICIWaRM) recently became the first United Nations Educational, Scientific and Cultural Organization (UNESCO) Category 2 Water Center in the U.S.



William S. Logan

William S. (Will) Logan said about 20 Category 2 Centers in various stages of approval are scattered in major regions worldwide, except Sub-Saharan Africa. The centers are committed to supporting UNESCO’s strategic objectives to render technical assistance, build research capacity and exchange information. They are designed to form networks and increase UNESCO’s impact and visibility.

An international agreement between the U.S. government and UNESCO preserved the semi-autonomous nature of ICIWaRM, which was the first such center in any field. “We are the

guinea pigs who went through this system for the United States,” Logan said, adding that the unique agreement may smooth the way for similar centers. Conceived about five years ago, ICIWaRM began as a UNESCO operation in 2009.

ICIWaRM’s focus lies at the confluence of UNESCO’s International Hydrological Programme (IHP), the U.S. National Commission for UNESCO and the U.S. government’s objectives for water resource management, remaining consistent with the objectives of the three arenas.

Headquartered at the U.S. Army Corps of Engineers Institute for Water Resources, ICIWaRM is not strictly a Corps activity but a mix of U.S. government, academia, nongovernmental organizations and other international organizations that work on integrated water resources management. Partners include several universities, the American Society of Civil Engineers, the Nature Conservancy and many others. Key partners also include other Category 2 Centers, such as the International Centre for Water Hazard (ICHARM) in Japan and the Centre for Arid and Semi-arid Zones of Latin America and the Caribbean (CAZALAC) in Chile, which works on arid zone hydrology. These projects may offer connections for Nebraska.

ICIWaRM focuses on practical science and technology, including engineering and policy. Instead of drilling wells in villages or engaging purely in university-style research, the center works in the middle zone. “We’re definitely trying to partner with these other institutions and definitely, as always, seeking collaborations,” Logan said.

He described several examples of ICIWaRM’s work. A project in conjunction with the World Bank and the Inter-American Development Bank in Peru is strengthening the capacity for participatory, integrated and basin-scale water resources management in several river basins. ICIWaRM is integrating structured participation, systems modeling and planning.

A second project involves working with CAZALAC, the Chilean center, to create a drought atlas for several pilot regions in Latin America and the Caribbean. Another project offers short courses in hydrologic modeling and related fields to build capacity by emphasizing customized learning. Instead of using the Colorado River as a model, for example, participants study their own systems, coming away with practical information.

The Water for Food Institute may benefit from joining as a Category 2 Center. As such, the institute could take advantage of an existing network of other UNESCO programs and centers, including participating on each other’s boards and attending regional meetings. “It provides a great network to plug into,” Logan said.

Logan described Florida International University’s partnership with ICIWaRM to develop a joint



Harvesting rainwater in India

program with the UNESCO-IHE Institute for Water Education to combine academic experience in the U.S. with an IHE degree. An exchange program between UNESCO-IHE and the University of Nebraska–Lincoln could be a valuable learning experience for students, he said.

“There are lots of good possibilities,” Logan concluded. “ICIWaRM would love to talk to you more about that.”

## Speakers

### Growing Enough Food Without Enough Water

#### David Molden

Deputy Director General for Research, International Water Management Institute

The solutions of the past won't solve the world's future water scarcity, David Molden said. He encouraged a holistic approach that fits each region's circumstances, from the rainfed fields of Sub-Saharan Africa to industrial society's own consumption and waste. Molden identified areas of opportunity, cautioned against old assumptions and proposed a new water agenda that could raise more food while also reducing poverty.

One-third of the world's population lives with water scarcity, but it manifests in two distinct ways: physical water scarcity, in which no additional water is available for further development; and economic water scarcity, in which water is available but access is challenged by policies, finances or lack of infrastructure. It is in areas of economic water scarcity, such as many parts of Sub-Saharan Africa, that solutions can be found, Molden said.

Enough food is produced today to feed the world's current population, but some people receive too much food, while a billion people receive too few calories. Raising the nutritional status of undernourished people, in addition to feeding an increasing population and meeting the growing demands for more meat, fish and milk, will require raising grain production by an estimated 70 to 100 percent. Calculations show one liter of water is required to produce one calorie of food, an astounding figure when considering the water needed to double food production. That requirement cannot be met using current production practices.



David Molden

#### The Water Agenda

Molden described four major pathways to meet future food and water demands:

- Improve water productivity by growing more food with less water in irrigated and rainfed systems.
- Expand irrigated and rainfed agriculture, a path followed in the past that Molden believes is limited today because of insufficient water and land.
- Promote trade from highly productive to less productive countries, a “virtual water” trade promoted by Tony Allen, winner of the 2008 Stockholm Water Prize. While calculations show that trade would save much water, countries tend to shift to greater self-sufficiency rather than more open trade during food crises, limiting the value of this option. “If you’re a core rural person, can you really rely on a trade system?” Molden asked. “I doubt it. And that’s why I think it’s extremely important for people to be able to produce their own food.”

- Manage the demand for water and food by consuming and wasting less.

“I think what it is, is not pointing the finger at farmers,” Molden said. “But this water and food equation is about all of us, right? It’s about our role in solving this big equation.”

### Rethinking Irrigation

Opportunities exist to improve water productivity, the amount of food that can be produced per volume of water. One opportunity can be found in the tremendous productivity variations in the world’s irrigated systems; some systems use water 10 times more productively than others. Improving under-productive irrigated systems is an important avenue for reducing the food gap while using less water. Another opportunity exists in the water productivity variations found within commodities, due in part to evaporation in low-yield areas. Beef and fish production operations also see large variations in water productivity, providing huge opportunities to improve livestock and fishery practices.

Despite these reasons for optimism, Molden also urged caution. The water and food community must rethink its view of irrigation. Irrigated systems may use water unproductively, thereby lowering yields, but they are not necessarily inefficient, the prevailing view. For example, in Chishtian, Pakistan, an irrigated agricultural

area, 90 percent of the available water is used for irrigated crops and cities, a highly efficient use of the available water with little left for the environment. That is a much different picture than the commonly held view that 60 percent of irrigated water is wasted. Chishtian uses the available water efficiently, but yields are low relative to the amount of water used.

*“We think about water and immediately most people start thinking about water and rivers and irrigation. Somehow we have to expand our minds about what water is, starting with rainfall.”*

“Efficiency, in a lot of cases, is not the real problem,” Molden said. “It’s overuse of water by irrigation. The real problem is the extremely low values of water productivity in these areas. With that same amount of water, it is possible to double water productivity, grow twice as much food with this amount of water.”

### Water Productivity and Yield

Crop breeding is another source of optimism and caution. In the past, crop breeding greatly improved water productivity, but those gains have leveled off, Molden said. Some understudied crops, such as the wheat alternative teff in Ethiopia, may still see water productivity benefits from improved crop breeding. But it’s important to consider that across many crops, water productivity rises faster at lower yields, leveling off at higher yields. In high-yield regions, when only slight gains in water productivity are achieved, even greater use of irrigation is encouraged. Yet increasing yields from 1 ton to 2 tons per cubic meter of water increases water productivity 74 percent.

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“What does that mean for us?” Molden asked. “That’s the hot spot. ... This is the area for the biggest potential for water productivity gains. This is also the area where there’s high poverty. If we can narrow in on that focus, we get two big wins at the same time.”

Tremendous opportunities to increase water productivity exist in rainfed agriculture, Molden said. The formula is simple: a little water, improved nutrients, drought-resistant varieties and field conservation practices to reduce nonproductive evaporation. “We think about water and immediately most people start thinking about water and rivers and irrigation. Somehow we have to expand our minds about what water is, starting with rainfall.” Growing more food using rainfed agriculture also would take pressure off river systems, improving resources in water-scarce areas.

Africa’s farming uses little irrigation. Rather than trying to expand irrigation, Molden believes the answer is to use other, smaller ways of getting

water to people. Even in the Nile Basin, where conflicts over irrigation and hydropower continue, few opportunities exist to expand irrigation. Little attention is paid to the enormous opportunities for upgrading rainfed and pastoral lands in that region.

### Holistic Solutions

Molden suggested de-emphasizing the distinction between rainfed and irrigated agriculture and focusing instead on a range of agricultural water management solutions, such as soil moisture. Of the available solutions in a given location, such as water harvesting, drainage and irrigation, which is the most appropriate?

The formula for success is there, but it isn’t being implemented fast enough. How, Molden asked, can we act faster? The answer lies partly with developing appropriate technologies. He cited a successful example in India where 70 percent of production comes from water obtained through small, portable pumps. Despite their popularity, the pumps are inefficient, expensive

and contribute significantly to greenhouse gases. A need exists to develop affordable pumps using alternative energy sources, which also could be used in Africa.

But the answer requires more than technological solutions, Molden urged. Supportive policies, social structure, land and ecological sustainability, and infrastructure are key components as well. Molden relayed a lesson from Matsepo



Michael K. Doane, David Molden and Robert T. Fraley

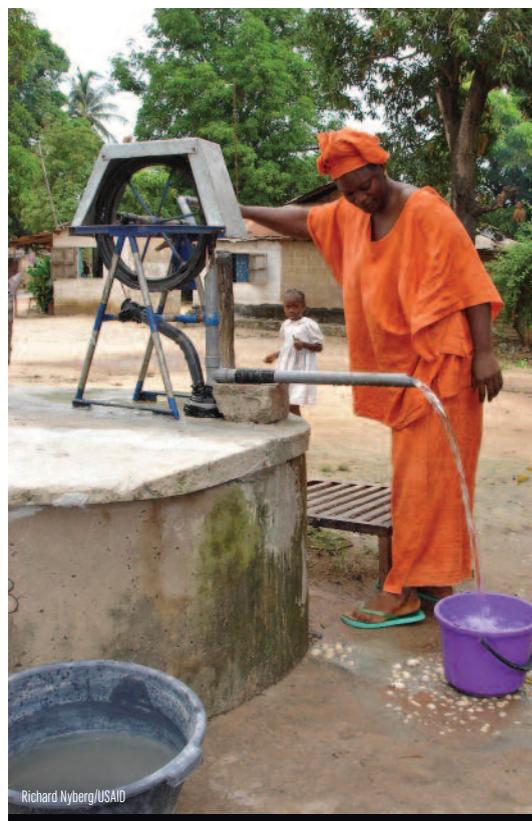
Khumbane, a South African woman who discussed the importance of “mind mobilization” to get past the paralyzing nature of poverty. That concept, Molden said, must extend to policymakers as well.

The water, food and livelihood agenda, Molden said, is about enhancing access to water for the poor, increasing water productivity in a way that enhances ecosystems, and transforming water governance and management.

The water and food community must look beyond seeds, pumps and fertilizer to big solutions, Molden said. He offered six solutions for the future:

- Upgrade rainfed systems with better water and soil management.
- Revitalize under-performing irrigation systems.
- Learn to manage groundwater sustainably.
- Reuse wastewater safely as more urbanites use wastewater as water sources.
- Transform water governance and management.
- Support these actions with better information systems.

Proceeding as before threatens Earth’s ecosystems and misses an opportunity to improve livelihoods and nutrition. Moving forward won’t solve water scarcity, but by working with farmers, the food and water community can raise people out of poverty and provide food to those who need it most. “I think we have to imagine working together,” Molden concluded. “And in that equation, it’s working with the farmers, the pastoralists, the governments and the managers of water resources. I think that’s the key: It’s partnership and moving forward.”



Woman pumping well water in Senegal

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### Water Sector Improvement through Participatory Irrigation Management in India

#### U.N. Panjiar

Secretary, Ministry of Water Resources, India

U.N. Panjiar described India's success reforming its irrigation management into a participatory system, which has resulted in increased water use efficiency, distribution equity and improved conditions for farmers.

India has 16 percent of the world's population but only 4 percent of its water resources and less than 3 percent of its land area. More than three-quarters of its usable rainfall arrives during a few spells of intense rain throughout the four-month monsoon season. Rainfall also varies geographically, with as little as 100 millimeters falling in the west and more than 10,000 millimeters in the northeast. About half of the country's area is cultivable, and more than 75 percent of that land is used for crops, divided almost equally between irrigated and rainfed agriculture.

If India continues with the productivity and efficiency levels prevailing today, projected demand in 2050 will far exceed water availability, Panjiar said. However, if India achieves its water efficiency and productivity goals by then, availability is expected to match demand. Because rainfall varies considerably temporally and geographically, water storage remains vital. Even taking current construction projects into account, per capita storage will remain low compared to the world average.



U.N. Panjiar

#### India's Water Challenges

India is facing many challenges in agricultural water productivity, including:

- Water availability per capita continues to shrink, from a comfortable 5,000 cubic meters in 1951 to 1,700 today.
- Surface water efficiency in irrigation, which uses more than half of the country's water resources, varies from 35 to 40 percent but could be improved to 60 percent.
- Water infrastructure is deteriorating from lack of maintenance.
- Inappropriate irrigation planning leads to environmental degradation, waterlogging, salinity and alkalinity problems, groundwater quality degradation, drying wells and increased energy consumption.

“Integrated and coordinated development of surface water, groundwater and use of

rainwater ... needs to be encouraged and incorporated at the planning stage itself so that the irregularities of fluctuating rainfall and the degrees of the fluctuating surface water can be mitigated,” Panjiar said.

Financial sustainability also is problematic. Often state governments, responsible for managing water resource projects, provide inadequate funds for maintaining irrigation infrastructure due to low water rates and the inability to collect fees caused by a disconnect between project authorities and water users.

The irrigation sector faces two major problems. First, poor use of irrigation facilities stems from incomplete canals and surface irrigation projects caused by contractual and legal issues. Project constraints and low water availability make it difficult to maintain systems. Farmers, the major stakeholders whose fortunes are most directly linked to system performance, have not been involved in management, Panjiar said. Although the governments are responsible for irrigation management, they have not attempted to train farmers in water management. Lacking a legal framework or empowering environment, farmers have had no incentive to learn or take over irrigation systems. Because water is provided based on irrigated areas, farmers have adopted inefficient irrigation practices and often grow water-intensive crops.

A second problem facing irrigation in India is inequity in water distribution. Lack of regulations and farmer participation has allowed farmers at the headlands to over-irrigate, leaving inadequate water supplies for farmers at the end of the canal system. The government’s inability to

maintain the irrigation infrastructure and ensure equity has “rendered the old irrigation system unsustainable and inequitable,” Panjiar said. “Adequate emphasis needs to be given to community participation, thereby ensuring the financial and physical sustainability of the systems. There is a need to have an enabling environment for empowering the farmers to take over the management of the irrigation systems, and this is what has been tried in India.”

### **Empowering Farmers to Manage Irrigation**

India has begun developing a participatory irrigation management system (PIM), creating 57,000 water-users associations to date. The associations’ objectives are to take responsibility for managing the infrastructure, distributing water equitably, using water efficiently for optimal agricultural production and settling disputes among farmers. The associations also ensure conjunctive use of rain, surface and groundwater, and develop community responsibility to collect water fees. The participatory approach ultimately develops a sense of ownership among the farmers and ensures sustainability of the entire system.



Agricultural fields in India

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Panjiar described the system's tiered layering and management as well as the associations' functions, including an assessment of water availability before the crop season and a social audit of water use afterward. Farmers can be penalized for violating the water schedules.

India has noticed many benefits from this participatory approach, Panjiar said. Farmer attitudes have changed. They pay water charges regularly and follow efficient irrigation practices, including shifting to less water-intensive crops following awareness training. The results have been considerable water savings and increased irrigation area coverage, which has improved farmers' incomes. Water once sufficient to irrigate for only eight months now irrigates year round. Farmers' feelings of ownership have led to increased interest in maintenance and scheduled enforcement, which also has created local jobs. Because farmers are looking after water regulation, overdrawing of water is declining.

The government returns between 30 and 100 percent of water revenue to the associations, which also levy additional charges for system maintenance, ensuring sustainability.

The central government developed a model PIM act and advised states to enact regulations that empower the water-users associations. To date, 15 of the 28 states have done so.

### A Success Story

Panjiar described the Waghad Project in Maharashtra state, where the PIM system has proven very successful. "The most important benefit that has occurred to the water-users associations is that it has created a sense of

ownership among the farmers," Panjiar said. "That's a really big thing."

Ownership has led to sustainable management practices, decreased operation maintenance costs, and resulted in a threefold increase in the average irrigated area. Water charges have increased sevenfold, but recovery of fees has gone from 60 percent to 100 percent. Participatory irrigation management in Waghad basin, and the consequent increase in water use efficiency, has resulted in water savings of 30 percent.

Farmers also have shifted from growing rice and wheat to cultivating grapes, a more productive crop. As their knowledge and confidence has grown, farmers have expanded their operations. "Earlier, they were supplying grapes to the wineries," Panjiar said. "Now they have decided to set up their own winery also, and they have launched a website of their own."

The result is an increase in year-round employment opportunities and in productivity, which has gone from 1 gram per liter of water to 5 grams per liter of water.

Panjiar concluded with a description of the Participatory Action Research Program, which aims to increase yields and income per drop of water. The technologies developed in the lab are being implemented on the farm. Field projects are demonstrating the efficacy of improved irrigation, conservation and agronomic practices, and are carried out in a participatory mode. The project has been welcomed by farmers and has led to water savings, improved crop production and increased farm community incomes.

## The Water-Saving Irrigation Strategy and Effect in China

### Shiqi Peng

Chief Scientist, National Agro-Technical Extension and Service Centre,  
Ministry of Agriculture, China

Although China has much irrigated land, it also has limited water resources, Shiqi Peng said. In the 1990s, China developed a water-saving irrigation strategy that has achieved tremendous success, although many challenges remain.



Shiqi Peng

An imbalance of water resources exists in China. The north has more land but insufficient water resources from either surface water or groundwater. The south has less land and more water resources but suffers from limitations in capturing the water, and building irrigation equipment is difficult and expensive.

Precipitation distribution also is uneven, with 60 to 70 percent of precipitation falling in summer and autumn. Annual precipitation can fluctuate 20 to 30 percent between wet and dry years. Drought may occur throughout the year in China, and extreme droughts occur frequently. Prior to the 1990s, China implemented flood irrigation throughout the country. Under that system, farmers are responsible for keeping more water in the soil and providing more water to their crops through flooding. The irrigation schedule follows the crop-growth period for irrigation to achieve a high yield. With soil scanners, more water is returned to the ground during delivery; only 35 percent of water is transferred to the field.

“China’s government has paid attention to developing water resources and irrigation systems for food security,” Peng said. Irrigated land reached 57.8 million hectares in 2007, which accounts for 47.5 percent of total cultivated land, concentrated in the east and south.

### Aspects of Water-Saving Irrigation Strategy

However, inappropriate management has caused many problems. To resolve some of those problems, the government developed a water-saving irrigation strategy, which contained five aspects. The first addresses supportive policy. The government issued an outline of development planning and cost-saving technologies to make

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strategic points clear. Then, special funding was budgeted to support key infrastructure construction, to establish demonstration projects and to give subsidies to farmers that allow them to improve water management and purchase agricultural machinery and irrigation equipment.

The second aspect deals with infrastructure construction. A special budget was used to rebuild soil canals with cemented liners or to replace them with pipes to reduce leakage during delivery. By 2007, 24 percent of the total irrigated land had received infrastructure upgrades.

The third aspect involves improved water management. Furrow irrigation, alternate furrow irrigation, rice shallow irrigation, rice shallow irrigation scheduling and land arrangement were privatized in China. The planting structure changed according to rainfall and water resources. For example, rice production decreased sharply in areas with insufficient water resources, while potato growing, which can delay the sowing period, replaced corn due to the spring droughts in the northwest. “Climate adaptability of planting is good for reducing irrigation water use,” Peng said.

The fourth aspect promotes increased use of modern irrigation equipment. Since 1996, through demonstration projects, the government has helped farmers purchase modern irrigation equipment, which has been used on many cash crops, such as vegetables and fruit trees. State farms and agricultural companies in the northeast try to use pivot irrigation because of large farm sizes. Small-scale farmers use drop systems and sprinklers.

The strategy’s fifth aspect introduces rainfed technology to irrigated land. More than 350 millimeters of precipitation falls in irrigated areas. Straw-covered soil, deep-loosening tillage and no tillage were introduced to combine with irrigation. These measures reduced evaporation and irrigation frequency and retained soil moisture. Some small ponds were built near fields to collect rainwater for supplementary irrigation.

The government’s water-saving irrigation strategy has greatly improved food production and water use efficiency. Irrigated land continues to expand with the same amount of water supply. Grain production also has increased. In 1996, gross grain amounts reached 500 million tons with the same irrigation water supply. Farmers’ incomes have increased threefold by using irrigation equipment.

The delivery rate of irrigation water increased from 35 percent to 48 percent, and the amount of water supplied decreased about 2,000 cubic meters per hectare from 1988 to 2007. Each increasing point indicates that about 3.4 billion cubic meters of water were saved during transmission. These results could feasibly increase new irrigated land by 520,000 hectares.

Water use efficiency also increased. Evaluations showed that about 70 percent of total grain came from irrigated fields. The relationship between consumption of irrigated water and grain output can be expressed as 1 to 1.1 on average in 10 years, a 27 percent increase compared to 1988. The national average of integrated water use efficiency reached 0.85 kilogram per cubic meter.

### New Water Challenges

Like other countries, however, China is facing serious water problems and new challenges.

Last year, the government announced its aim to increase grain production capacity by 15 million tons by 2020. That increase will require about 42 billion cubic meters of new water with current technology. Where will that water come from? Peng asked.

The water supply is not increasing. The proportion of agricultural water use has declined and irrigation water has remained between 340 billion and 360 billion cubic meters since 1978. In addition, cash crops are a

new area for agriculture development. Vegetables and fruit trees have increased, accounting for about 20 percent of agricultural water use. If farmers maintain traditional irrigation methods, cash crops will consume more water compared to grain crops – a serious concern, Peng said.

Other problems include yield loss due to a greater frequency of droughts and the changing structure of agricultural labor that makes it difficult to adopt new technologies. For example, if farmers receive equipment but do not know how to use it, it will quickly be discarded.

How can China increase its water supply, and how can water be used in agriculture? Peng asked.

Research has shown that total water resource consumption for agriculture is about 716 billion cubic meters a year, with 43 percent from irrigation water and 57 percent from precipitation. Therefore, it is important to combine rainwater technology in irrigated areas.

Other solutions include increasing the application of modern irrigation technology where conditions permit, as well as continuing to strengthen the agricultural infrastructure and to boost high-standard farmland construction, which China has already begun. Integrated water use efficiency combined with agronomics should increase in the future. “It has great potential, especially in the northwest and the southwest,” Peng said.

*“China’s government has paid attention to developing water resources and irrigation systems for food security.”*

China also must strengthen training for technicians and farmers. County-level technicians must improve their ability to provide technical guidance and service to local farmers.

Other areas of needed improvement include water allocation, information technology, new varieties and social services.

China pays great attention to agricultural water use, Peng concluded. The implementation of the water-saving irrigation strategy has achieved great results, but water-saving agriculture involves many departments and technologies. “We have a long way to go,” she said, adding that China hopes to work with other countries to improve the technical level of water use and management and to promote sustainable development of agriculture and food security.

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### Population, Food and Water: Role of Water Management in Global Food Production

#### Krishna C. Prasad

Senior Lecturer in Land and Water Development, UNESCO-IHE, Netherlands

Krishna C. Prasad offered perspectives for increasing available water supply, the social consequences to rural farmers in developing countries, and approaches the UNESCO-IHE Institute for Water Education takes to meet these challenges.



Krishna C. Prasad

The International Institute for Hydraulic and Environmental Engineering (IHE) was incorporated into the United Nations Educational, Scientific and Cultural Organization in 2001 to reflect UNESCO's priority of addressing water issues.

About 80 to 90 percent of the world's potential to double food production – such as obtaining higher yield per hectare through double- or triple-cropping and modernizing existing or installing new irrigation systems – can be found in existing cultivated areas. Land reclamation provides promising venues for another 10 to 20 percent of potential yield increases.

Prasad said research has demonstrated that 80 percent of future water stress will come from population and development, not from climate change. Given that, are current capacity-building activities appropriate? Prasad asked. For example, 85 percent of U.S. global change research funding is devoted to climate and carbon.

#### Population Dynamics

An additional problem stems from lumped estimation of population dynamics. Developing countries tend to be considered together, but they are not homogeneous. There are profound differences between the least-developed countries and emerging countries. “It may be more useful to see the difference between those two categories and compare it across the whole spectrum,” Prasad said.

In emerging countries whose annual per capita income ranges from \$1,000 to \$12,000, growing economies are driving farmers into cities, resulting in substantial migration from rural to urban areas. The increasing urban demand for food pressures farmers to expand farm sizes and adopt mechanization. Producers grow higher-value crops to make a living on smaller plots, and many farm part-time, working jobs in industry or the service sector as well.

In contrast, low-producing farmers comprise most of the population in least-developed countries. They are extremely constrained by lack of inputs

and resources to increase productivity. Prasad said weak institutional capacity inhibits their ability to adopt technological or economical interventions.

Developed countries are characterized by a low agricultural share of gross domestic product. Farmers represent only about 2 percent of the population, but their productivity is about 500 times that of small-scale farmers in less-developed countries.

Population levels have stabilized in developed countries, but continue to grow in the least-developed and emerging countries. In each country category, a large percentage of cultivated areas lack water management systems or have weak irrigation systems. Interventions are possible in all regions, but solutions will vary.

“The combinations of technological measures in the given settings, also institutional conditions of those regions or those countries, have to be matching,” Prasad said.



Market in India

Urbanization poses an interesting dilemma, he said. Cities with more than 5 million people are increasing dramatically. The typical farmer must decide whether to switch to a bigger farm or

move to the city. At the same time, pressure to provide food at an affordable price to urban people increases. Without a mechanism to help farmers expand, they must migrate to the city for alternative ways to make a living.

#### **Capacity Building through Education and Research**

One important challenge is more effectively turning scientific findings into practical technologies and improving economics and institutions, especially to support poor farmers in the least-developed and emerging countries.

Prasad highlighted approaches UNESCO-IHE is taking to address this challenge. With a mandate from the United Nations, the organization focuses on building capacity through education and research. It strives to be demand-driven and not just consider the supply perspective. Engaging in global partnerships is key, he said, particularly with the least-developed and Muslim countries, to help citizens implement solutions.

UNESCO-IHE focuses on impacts of global trends in population growth and increases in living standards; design, operation and maintenance aspects of water management systems; institutional aspects and stakeholder participation; and environmental, social and financial aspects of water management.

Pathways for achieving these foci include institutional reform through establishing mirror sites in partner countries; access through alumni and regional nodes in countries; and development of innovative educational activities to fill capacity gaps so countries can address problems internally through means such as distance education and double-degree programs.

## Speakers

### Going from 1 to 3 Tons Per Hectare in Africa with More Variable Rainfall

#### Pedro Sanchez

Columbia University Earth Institute, 2002 World Food Prize Laureate

Programs designed to help farmers increase agricultural production are much less costly ways of feeding hungry people than food aid programs, Pedro Sanchez said. He outlined recent successes in tripling Africa's cereal crop production from 1 ton to 3 tons per hectare without increasing water needs.

African farmers average just 1 ton of cereal crops per hectare, the lowest output of any region in the world. By contrast, Latin America and South Asia produce 3 tons per hectare, China produces 5 tons, and North America and Europe produce about 10 tons per hectare. Africa's low output stems from two overarching problems: unhealthy soils depleted of vital nutrients, such as nitrogen and phosphorus, and untamed waters, such as surface-sealed soils that prevent water from penetrating.

"I'd like to redefine the goal of the Green Revolution as going from 1 to 3 tons per hectare," Sanchez said. "And I'm using corn mostly because it's the most important crop in most of the areas in Sub-Saharan Africa. We think this is perfectly feasible."

Sanchez cited evidence from two studies. The first comes from the Earth Institute's Millennium Villages project, in which 80 villages clustered around 14 areas throughout Sub-Saharan Africa – all hunger hot spots – are empowered to accomplish the U.N.'s Millennium Development



Pedro Sanchez

Goals, particularly those related to hunger. The project's approach is science based but community led. When asked, villagers unanimously agreed they needed farming goods and a clinic. Farmers were given subsidized fertilizer and hybrid corn seed.

Corn yields doubled in the study's seven Millennium Villages, each with about 1,000 smallholder farms. Prior to intervention, corn

yields averaged about 1.7 tons per hectare. After providing subsidized farming inputs, yields increased to an average of 4 tons per hectare.

In 2008, input costs and corn prices increased. At those rates, the input costs to produce an extra ton of corn averaged \$135. By contrast, the same ton of food delivered through food aid cost \$812 – a 6-to-1 ratio. “If you want ... to get people food so they can eat for a day, it will cost you six times as much as if you empower people to produce their food,” Sanchez said.

*“I’d like to redefine the goal of the Green Revolution as going from 1 to 3 tons per hectare. ... We think this is perfectly feasible.”*

In addition, the percentage of households with maize yields greater than 3 tons per hectare or equivalent in other crops jumped from less than 10 percent to 78 percent; the percentage of households without food for at least one month per year dropped from 69 percent to 35 percent; and the percentage of stunted children (caused by chronic malnutrition) under two years of age decreased from 50 percent to 36 percent. Sanchez cited improvements in other health indicators from increased use of malaria bed nets to improved sanitation and decreased child mortality, from 125 deaths per 1,000 live births to 50.

“The point I’m trying to make here: There’s a lot more than just increasing food,” Sanchez said. “All these things have to be together. What’s the point of having high production, if people are dying of malaria or the kids are

dying of malnutrition? Or vice versa: What’s the point of having tremendous health services if people can’t produce food? The Millennium

Villages have been working on the integrated approach, and I’m a strong believer in it.”

### **Africa’s First Green Revolution Country**

Sanchez’s second source of evidence that tripling Africa’s yields is feasible comes from Malawi, Africa’s first Green Revolution country. In 2005, then new President Bingu wa Mutharika wanted to help the country’s farmers produce more corn. At the time, Malawi was

importing 45 percent of its food to feed its 13 million people. The Millennium Project Task Force recommended subsidizing fertilizers and hybrid corn seed. Perplexingly, the world’s major donors – the World Bank, U.S. Agency for International Development and others – refused to subsidize African farmers. “You scratch your heads and say, ‘Aren’t we subsidizing American, European and Japanese farmers to the tune of a billion dollars a day? What’s wrong with this picture?’”

Malawi’s president decided to proceed anyway, and despite scarce resources and limited infrastructure, managed to get fertilizer and seed to 1 million of Malawi’s 2 million smallholder farms in time for the planting season. Production increased dramatically. In 2005, before the subsidy program, Malawi produced 1.3 million tons, averaging 0.81 tons per hectare, a 43 percent deficit in the country’s

## Speakers

food requirement. In the first year of the program, Malawi's production nearly doubled, with an 18 percent food surplus. The following year, in 2007, Malawi reached 3.3 million tons, averaging 2.04 tons per hectare. With the 57 percent food surplus that year, Malawi became a maize exporter and food aid donor to neighboring countries. That year, subsidies cost \$70 million but returned \$688 million.



Richard Nyberg/USAID

Woman exchanges produce for USAID seed vouchers

Much of Malawi's soils suffer from lack of nitrogen, and some areas also experience dry spells at critical times in the growing season. Sanchez and his team are developing a digital soil map of the world to better manage local needs, by pinpointing areas requiring additional nutrients or erosion control and identifying regions that have a higher probability of drought stress. Malawi will be the first country with a detailed digital soil map.

Sanchez acknowledged that ridding Malawi and other African countries of poverty will require more than producing 3 tons per hectare of maize. Changes in farming practices, such as encouraging small farms to switch from maize to crops like vegetables and fruits, and improving business capacity, are needed. Some of this is already happening. Mobile banks, for example, allow villagers to secure their money and obtain loans.

Successes in Malawi spurred an effort to launch a global fund for smallholder agriculture, similar to The Global Fund to Fight AIDS, Tuberculosis and Malaria. On April 17, 2010, the Global Food Security Trust Fund was launched, with support from the World Bank, the Bill & Melinda Gates Foundation and several world governments, including the U.S., Canada, Japan and Spain. To date, 10 other African countries are following Malawi's lead.

### The Green Revolution Bonus

Increasing yields in tropical Africa from 1 ton to 3 tons per hectare can be achieved without increasing water, Sanchez said. He challenged the commonly held view that the proportion of plant transpiration to evapotranspiration is relatively constant. He cited a study by Johan

Rockström and his colleagues demonstrating that that constant is true from about 4 tons to 10 tons per hectare of grain yields. At 1 ton per hectare, however, the proportion of transpiration to evapotranspiration is about 15 percent because the space between plants leads to high evaporation. But at 3 tons per hectare, transpiration is more than one-third of the equation, and by 5 tons it's about two-thirds.

“This is what I would like to call the Green Revolution bonus because as you go from 1 to 3 tons per hectare, you can get a lot more water,” Sanchez said.

Although studies have shown mixed results from fertilizer inputs in rainfed agriculture, inputs are still valuable additions in the long term, despite risks of crop failures. Inputs result in better root systems, and greater yields per hectare allow more water vapor to flow through transpiration than through evaporation.

“We’d love you to have a boarding pass on this plane and join us in this exciting adventure,” Sanchez concluded. “It’s happening. One to 3 tons per hectare can happen in the next 10 years.”



Malawi farmers show harvested ears of maize.

3





GENETICS AND PHYSIOLOGY  
OF CROP WATER USE

# Genetics and Physiology of Crop Water Use

## Panel

### **Marty Matlock**

Professor of Ecological Engineering, University of Arkansas

### **Sally Mackenzie**

Ralph and Alice Raikes Chair, Plant Sciences, and  
Director, Center for Plant Science Innovation, University of Nebraska–Lincoln

### **Roberto Tuberosa**

Professor of Biotechnology Applied to Plant Breeding, University of Bologna, Italy

### **Richard Richards**

Chief Research Scientist, Commonwealth Scientific and  
Industrial Research Organisation (CSIRO), Australia

### **James Specht, Moderator**

Haskins Professor in Plant Genetics, University of Nebraska–Lincoln

*The session explored key issues and challenges in developing crops that can produce more yield with less water, including plant breeding techniques, corn water use modeling and transitioning plant innovations from the laboratory to the field. The panelists brought many years of experience and perspectives from different areas of expertise. Each panelist gave an overview of his or her subject area and the panel then responded to audience questions.*



From left: Sally Mackenzie, Roberto Tuberosa, Richard Richards and Marty Matlock

## A Global Assessment of Corn Water Use As Affected by Climate, Genetics and Scarcity

**Marty Matlock**, University of Arkansas

Marty Matlock described a high-resolution water assessment model he and colleagues are developing to determine how much water corn uses globally and to evaluate the balance between rainwater stored as soil moisture (green water) and water from surface water or groundwater sources (blue water). With a framework for assessing these characteristics, the model can analyze various scenarios, such as climate change and water demand by region.

“Our quest is to develop a modeling framework that has utility for decision-makers,” Matlock said.

To achieve high resolution, Matlock and his colleagues divided the globe into geospatial resolution cells of 5 minutes by 5 minutes, or about 10 kilometers by 10 kilometers. After inputting data for each cell, the researchers ran the model to determine yield. Comparing the results between the model’s predicted yield and observed data, the model was calibrated using high-resolution input and yield data available for the U.S. heartland (Corn Belt). From potential yield data, researchers can determine water demand.

Matlock and his colleagues chose the CERES-Maize simulation model embedded in the Decision Support System for Agrotechnology Transfer (DSSAT) because it uses daily rainfall inputs. It is therefore sensitive to critical threshold water scarcity, a more important element for kernel development than annual rainfall. Using the CERES model required collecting and entering daily data sources into each cell for each



Marty Matlock

characteristic. Temperature and radiation data were acquired from the Climate Research Unit; precipitation data were acquired first from the Tropical Rainfall Measuring Mission and later from the National Climatic Data Center; and soil characteristics came from the ISRIC-World Inventory of Soil Emission Potentials soil dataset.

After running the model, Matlock’s team assessed its predicted values against global crop yield data obtained from Foley et al. published in *Science* magazine in 2005. The model did well in dryland regions, but predictions did not match observed yields in wetter regions. To calibrate the model using the highest geospatial resolution yield data, they focused on the U.S. heartland region, inputting high-resolution soil, temperature and rainfall data.

“We’re modeling one stalk of corn and extrapolating that to the world,” Matlock said. “If I really wanted this model to be right, I’d quit right now. All models are wrong; some models are useful. The question is, is there utility with this

## Genetics and Physiology of Crop Water Use

model? And I would argue that, yes, there's strong utility because of its process-based development.”

To establish the model's parameters, Matlock and his colleagues developed a set of parameters based on what other researchers use to model at the field or plot level. They first performed calibration runs on a 40-county region, then on a larger region spanning several hundred counties. For single cultivars, the model is sensitive to the four parameters that define the way a single corn stalk responds to precipitation and temperature. In the case of a single cultivar, the predicted versus observed graphs were not effective. However, modeling using nine cultivars and selecting the cultivar that best fit yield resulted in good calibration between predicted and observed yield. Mapping the results showed these four variables are associated with other important variables as well.

The next step will be evaluating the model's ability to adequately predict water use. The model then can be used to analyze land use impacts on blue water resources; to determine a stress-related water footprint using regional stress factors; and to develop a series of water stress indices, including the impact on base flow under various scenarios, such as climate change, population change and industrial demand.

A lack of regional high-spatial and high-temporal data remains a problem, Matlock said. In addition, he continued, “We lack integrated models for the outcomes of concern: the ‘so what?’ part. We have to build that from scratch because life cycle assessment, risk-based models just don't cut it for these sorts of social and economic impacts.”

### Plant Research Innovations in the University: When Will They Apply to the Real World?

**Sally Mackenzie**, University of Nebraska–Lincoln

Despite tremendous innovations in plant research today, the challenges of integrating research into the real world leave many of those innovations stuck in the laboratory, Sally Mackenzie said. She described the approach taken by the Center for Plant Science Innovation at the University of Nebraska–Lincoln (UNL) to move research to the field.

Some of the research occurring in universities includes innovations to improve seed nutrient content, modify plant architecture for water use efficiency and alter properties to enhance shelf life.



Sally Mackenzie

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Many innovations stem from the ability to sequence the genomes of major crop species, which is helping researchers understand the genes and mechanisms that one day may improve plant tolerance to drought and other beneficial characteristics.

These innovations and capabilities are already happening in the laboratory, Mackenzie said, adding that “the innovation is not what limits our ability to actually come up with some interesting solutions.”

If universities have laid the technological groundwork, why are they not real players in the dialogue? she asked. On most campuses, the link between the lab and true agriculture biotechnology is nonexistent. In contrast, the Center for Plant Science Innovation is building its approach around taking research to the field. Such an approach requires four things:

- Broadening in-house capabilities in crop transformation. On most campuses, transformations stay in model species in the lab.
- Building capacity for large-scale, APHIS-compliant transgene field testing to see whether transformations will come to fruition.
- Designing a critical mass of researchers to facilitate interactions, a “center” concept that often fails because the departmental nature of university settings hinders the free flow of ideas.
- Providing cross-departmental and cross-disciplinary accessibility, a huge challenge facing university researchers, particularly in interacting with government researchers.

Although UNL’s center has met each of these requirements, moving to commercialization remains challenging. Much of the problem lies with the U.S. regulatory system, Mackenzie said, which often requires case-by-case review by at least two regulatory agencies before innovations can be grown large scale. The process creates paperwork and enormous expense that can preclude public sector participation.

“The innovations sit on the shelf, and this is going to be a huge challenge, I predict, for the Bill & Melinda Gates Foundation and for anyone else who really wants to integrate these kinds of technologies,” Mackenzie said. “There are really two conduits to allowing anything to come out for public use, and that’s right now, as far as we’re concerned, DuPont and Monsanto.”

These companies have the ability to manage the regulatory process, but their involvement is limited compared to the available innovations. The average American consumer is unwilling to pay more for many valuable products that, for example, enhance growth capability in response to abiotic stress, Mackenzie said. This situation creates a logjam for biotechnology opportunities.

To help UNL participate in moving innovations to the field, the university is establishing Nebraska Innovation Campus, a collaboration of academia, industry and government. Other universities are establishing similar opportunities to let researchers participate more meaningfully in moving needed innovations from their laboratories to real world applications.

# Genetics and Physiology of Crop Water Use

## Mapping and Cloning QTLs for Drought Tolerance in Durum Wheat and Maize

**Roberto Tuberosa**, University of Bologna, Italy

Roberto Tuberosa presented data on research projects for mapping and cloning quantitative trait loci (QTLs) to increase yield in durum wheat and maize. QTLs are stretches of DNA closely linked to two or more genes that underlie a phenotypic characteristic. Both projects used forward genetics, in which biparental crosses identify the genes and QTLs underlying the crop's adaptive response to drought. The genes' DNA can then be sequenced and annotated. "The reason I like the QTL approach is that we ask the plant, 'What is important?'" Tuberosa said. "We do not go in with a preconceived hypothesis. I personally think it's a little bit dangerous, particularly when we deal with complex traits such as drought tolerance, to go in with the candidate gene approach."



Roberto Tuberosa

### Wheat QTL Mapping

Tuberosa described finding a QTL important for drought resistance in durum wheat. Drought tolerance is important because sensitivity to

drought not only decreases yield but also impairs the flower's quality and the quality of the final product. He defined drought tolerance as not merely surviving drought, but also producing high yields under a wide range of water availability. Tuberosa collaborates with the seed company Produttori Sementi Bologna.

The project's objective, which Tuberosa coordinated among 10 partners throughout the Mediterranean Basin, is to identify QTLs for yield water use efficiency in related strains, grown across environments with a broad range of water availability. Researchers used biparental, or linkage, mapping with Svevo and Kofa, a durum desert wheat grown in Arizona. In rainfed and irrigated field trials, the researchers obtained a tenfold range in yield, demonstrating the negative effect of drought and allowing them to test the mapping population across a broad range of yield potential. Interestingly, the morphophysiological trait that best correlated yield with the environment and genetics was peduncle length.

Tuberosa and his colleagues identified two major QTLs on two different chromosomes that account for a large portion of phenotypic variation among the genotypes tested. A significant portion of the phenotypic variability stems from the QTL interactions. Grain weight had the largest effect on yield. Now, the researchers are fine-mapping and cloning the QTLs and both chromosomes in conjunction with the TriticeaeGenome project.

### Maize QTL Mapping

Tuberosa's QTL mapping and cloning research in maize focused on two traits important for drought tolerance: root architecture, because of its importance in avoiding the negative effects of drought, and flowering time, because phenology is the most important trait enabling plants to complete a life cycle before drought stress damages yield.

A wind storm had caused stalk lodging in an isogenic line with high root abscisic acid (ABA), but not in the line with low ABA. The team discovered that high-ABA plants had a higher root clump. Test crosses in both well watered and water-stressed conditions performed by collaborator Yu-Li in China demonstrated a significant effect on grain yield. Notably, the most productive genotype had a lower root mass.

They discovered the opposite effect in another recently isogenized QTL for root architecture, underscoring Tuberosa's point that "different QTLs, but also the same QTL, can have different effects according to the genetic background."

Tuberosa described a process to shortcut moving from QTL coarse-mapping to fine-mapping using introgression line libraries instead of isogenization. To date, he and his colleagues have identified three major QTLs and are fine-mapping one.

Genomics provides many opportunities to identify candidate genes for yield and traits important for drought resistance, Tuberosa concluded, but phenotyping remains the major constraint.

## Breeding for Water Productivity in Temperate Cereals

### Richard Richards, CSIRO, Australia

Richard Richards is optimistic that water productivity can be doubled in many environments but believes advances will be gradual. He described his successes using a trait-based approach to developing improved varieties of wheat and other temperate cereals.

Richards emphasized the need to develop a benchmark for water use efficiency by eliminating concepts such as drought tolerance and drought resistance that are not easily measurable and may be unrelated to productivity.



Richard Richards

## Genetics and Physiology of Crop Water Use

Benchmarking would allow scientists to measure improved genotypes and farmers to compare successes from year to year or from changes in practices. “I really want to get rid of this idea of drought tolerance and drought resistance,” Richards said.

Conventional breeding has been remarkably successful and will continue as the cornerstone of improvements and the benchmark for future gains. Yet, despite tremendous yield gains from new varieties, these successes are not enough. Greater yield improvements are needed.

Richards described the logical relationship between water use and yields. Soil evaporation sets a lower limit of water required to obtain any yield, but as available water increases, yield does, too. That relationship’s slope forms a boundary limiting potential yield based on available water. Yet, most farms’ yields fall well below the current potential. Filling the gap between actual and potential yields would double production, Richards said.

Improving management systems, such as stubble retention and earlier sowing, would have the biggest impact on filling that gap. “They’re going to have a much more immediate impact; they’re going to be adopted more widely; and that’s where the biggest gains are going to be made, in many cases,” he said.

But better genetics is also important, and surprisingly, the most important genes for drought resistance are those that promote a healthy root system. Water productivity in dry environments requires a healthy root system to use the water and nutrients effectively. Therefore,

genes that resist rootworm and cereal cyst nematodes and tolerate acidic soils have provided major breakthroughs in drought resistance.



Harvesting wheat from experimental plots

By improving the factors limiting water productivity, it is also possible to raise the maximum potential yield beyond current levels. Because heritability for yield is low in highly variable rainfed systems (a high-yield variety one year may produce a low yield the next due to different conditions), Richards and his colleagues use a trait-based approach to find new water-productive varieties. Other advantages to a trait-based approach include the ability to focus on genetic variability for the most important trait; faster genetic gains because the heritability of the trait may be higher than yield; more cost-effective evaluations other than yield; ability to conduct work out of season; greater amenability to marker-assisted selection; and the potential to pyramid multiple yield-enhancing traits.

To increase yields in a water-limited environment, a selected trait must increase water use, water use efficiency or harvest index. One example of a successful variety developed using this approach involved a trait that selects for 13C molecules, which offers a 10 to 12 percent yield advantage in very dry environments. A variety packaged

with this and other beneficial traits, such as disease resistance, was released.

Richards and his colleagues are working on other traits believed to be extremely important in dry environments, including seedling establishment, shoot and root vigor, and transpiration efficiency. Surprisingly, they found it most effective to select for each trait under favorable conditions rather than unfavorable or drought conditions. Although they have identified quantitative trait loci (QTLs), which are stretches of DNA closely

linked to two or more genes for a trait, they have found selection for phenotype, not markers or QTLs, to be the most efficient selection method.

“The phenotype is the limiting factor in every single case,” Richards concluded. “Important traits for crop improvement are complex, and in many cases molecular markers, or QTLs, may not be very effective. [Phenotypic information] is the massive challenge ... and we’ve just started to realize this.”

## Questions and Answers

**Moderator James Specht:** *What are the biggest possibilities for accelerating yield productivity rate of gain?*

Richard Richards sees enormous opportunities in improving the overall health of root systems. “I think it’s an area of absolutely essential investment in the future,” he said. “I think we really have to understand what’s going on below ground to make further gains.”

Roberto Tuberosa considers genomics an important tool to increase genetic variability and the heritability of beneficial traits. Knowing the exact gene or quantitative trait locus limiting a useful trait provides opportunities for manipulating that trait. Close collaboration with breeders who understand the limiting factors in the field is necessary.

Sally Mackenzie agreed that an integrated approach is necessary, particularly for under-

standing phenotypes. Scientists have examined phenotypes from a genetic perspective without understanding the metabolic phenomena underlying the processes. A greater understanding of metabolic biochemistry is needed, and that will take a systems approach.

**Audience question:** *How would you recommend distributing limited resources to improve water use efficiency?*

Mackenzie would put more funding into broad, interdisciplinary training in the plant breeding community, particularly as technologies integrate.

Richards agreed, adding that integration must include farmers who, with their intimate knowledge of growing crops, will make important observations and should be encouraged to work with academia. He also emphasized the need for bold initiatives, such as the International Rice Research Institute’s C4 Rice Project.

# Genetics and Physiology of Crop Water Use

Marty Matlock believes information technology is an important area for funding, noting the highest levels of technology for earth observation available to U.S. farmers come from the French and Indian governments.

Tuberosa suggested rethinking what plant breeding means and training plant breeders to coordinate teams of different specialists and to recognize the value of each piece. “The entire interdisciplinary effort has a bigger value than the value that each single person brings into this relay.”

**Audience question:** *What advice would you give young scientists starting in the field?*

Mackenzie described UNL’s educational approach, which emphasizes training students to integrate and manage new biotechnologies and comply with federal guidelines; capitalize on bioinformatics; communicate effectively; and understand and influence policy.

Tuberosa believes private-public partnerships are valuable avenues for training graduate students to work in teams and produce research more easily translatable to seed industry and farmers’ needs.

Richards urged students to find their passion and to seek collaborators. “The more you can collaborate and the more you can discuss, the more value you’re going to have, the more success you’re going to have.”

**Audience question:** *What are the key improvements necessary for modeling water use efficiency, such as data availability and focusing on potential rather than actual yield?*

Data availability is the biggest limitation, Matlock answered. It is impossible to calibrate or validate a model without knowing “what was.” Potential yield also is a critical variable. However, it is impossible to evaluate the impact of changing environmental conditions, climate or resource availability on actual yield using potential yield. Both are necessary.



Irrigated fields under conservation agriculture in Mexico

**Audience question:** *What is Richards’s experience with canopy air temperature as a wheat-screening tool?*

It’s an exciting area of research, Richards said. The coolness of the canopies has been an important selection tool but greater understanding is needed to fully harness it.

**Audience question:** *Why does Tuberosa urge caution regarding the candidate gene strategy?*

The more complex the trait, the less heritable it is, Tuberosa responded. The relationship between a specific gene and a phenotype becomes blurred. In those situations, the candidate gene approach becomes less effective, or at least riskier.

**Audience question:** *To what extent do epigenetic factors contribute to breeding programs?*

Epigenetics plays a huge role in traits, Mackenzie answered. For example, perturbing the mitochondria can reprogram the plant to grow fundamentally differently in response. However, understanding how epigenetics will influence breeding strategies is just beginning.

**Audience question:** *The highest-yielding cultivars in irrigated conditions often produce the highest yields under stress conditions, as well. Is it symmetrical, or is it a process of selecting genotype by environment?*

Richards said he emphasizes selecting under favorable environments because it maximizes genetic variants; therefore, heritability is higher, and greater genetic gains are made. In a bad year, those yields may be the lowest, but farmers are unlikely to do well regardless.

**Audience question:** *Maize and rice are sensitive to drought stress at flowering. Does Richards believe that selection for tolerance to stress at flowering without directly selecting under stress is possible?*

Richards described the mechanism that causes sterility under stress conditions. If researchers can keep some of the genes that switch off, causing sterility, to remain on, fertility of the pollen grains will increase. “It’s an exciting area of research, and I think it’s going to have massive consequences in so many of our crops,” he said.

**Moderator Specht:** *Concluding remarks?*

“What is good in nature for survival, I don’t think is good for crops,” Tuberosa said. Sometimes researchers must “fool” the crops into not reacting strongly to environmental cues.

Understanding how Mother Nature has learned to survive difficult environments provides important clues for crops, Mackenzie said. “But I would tend to agree these really drought-hardy materials that we’ve been able to come up with would probably not be of much agronomic interest.”

Matlock suggested moving beyond thinking of information as privileged toward a corporate reporting framework that encourages information to move from the laboratory to the field and higher “so that we can actually inform our future rather than react.”

Richards appealed to the youngest audience members to be excited by the challenges and to integrate and discuss ideas as much as possible. “I want to emphasize the value of our young people here and the potential impact that they can have in some very, very exciting areas of science in a very, very uncertain world.”

4





HUMAN DIMENSIONS OF WATER  
FOR FOOD PRODUCTION

# Human Dimensions of Water for Food Production

## Panel

### **Jason Clay**

Senior Vice President of Market Transformation, World Wildlife Fund

### **Elijah Phiri**

Leader of the Comprehensive Africa Agriculture Development Programme (CAADP) Pillar 1, University of Zambia

### **Lilyan Fulginiti**

Professor of Agricultural Economics, University of Nebraska–Lincoln

### **Richard Perrin**

Jim Roberts Professor of Agricultural Economics, University of Nebraska–Lincoln

### **Mike Young**

Executive Director, The Environment Institute, University of Adelaide, Australia

### **Raymond Supalla, Moderator**

Professor of Agricultural Economics, University of Nebraska–Lincoln

*The session focused on economic and policy issues surrounding water use for agriculture in developed and developing nations. Topics included food security in developing nations, agricultural water use in Africa, government policies for managing water in Australia, and environmental impacts and sustainability of global water use. Panelists gave overviews of their subject areas and the panel then responded to audience questions.*



From left: Elijah Phiri, Lilyan Fulginiti, Mike Young and Richard Perrin

## Feeding 9 Billion and Maintaining the Planet: Meeting the Challenge of 2050

**Jason Clay, World Wildlife Fund**

*Presented by Marty Matlock, Professor of Ecological Engineering, University of Arkansas*

Environmental concerns, which fall outside normal market powers, require special incentives and consideration in water resource decisions, Marty Matlock said.

Given that the world's population now consumes past the point of sustainability, should sustainability be a market choice for consumers? "This should be pre-competitive," Matlock said. "The consumers should have confidence that everything they buy complies with a certain threshold of humanity, of behavior, of ethics and sustainability."

The market has the power to move materials, goods and services from areas of plenty to those of scarcity. The problem is that the market is not responding to water scarcity, in part because crops are grown where there is no water. For example, in Brazil, areas that once were rainforest now grow 2.4 crops annually for export to China. "They're exporting de facto water to China," Matlock said.

Another example stems from the 1 billion people who lack access to water and the 2.4 billion who don't have basic sanitation. Every day, waterborne diseases kill 5,400 children. "That's the cost of this failure of technology – failure of civilizations," Matlock said. "It's a pretty dramatic cost."

Global climate change will increase water scarcity in already water-stressed areas.

How will financial institutions deal with increased investment risk in farming as floods and droughts increase, leading to critical losses? The problem is not just environmental; it's economic, Matlock said.



Marty Matlock presenting for Jason Clay

Although agriculture no longer accounts for 90 percent of global water use, as it did in 1900, agricultural water use has increased fivefold since then. Competing with other sectors for limited water affects the many other uses that are not monetized, such as biodiversity. The Colorado and Ganges rivers offer examples of dramatic decreases in water discharge due to overallocation. Peak flows have not changed, but critical base flows have dropped considerably over time. "It's hard to have a functional, viable aquatic ecosystem without the aquatic," Matlock said.

Rice, which accounts for 15 percent of human water use, presents another problem. But improvement is possible, Matlock said.

## Human Dimensions of Water for Food Production

Anheuser-Busch InBev, for example, achieved 4.7 percent per-unit reductions in rice culture, saving 3.5 billion liters of water in five years.

Water intake is only one issue; equally important is water effluent. From an ecological standpoint, given grossly limited incentive funding, Matlock believes profitable production practices should not be incentivized. “If you already have an incentive for conserving water – reducing soil erosion – then we don’t need to give you more money to do that which you ought to be doing anyway, because the marketplace will weed you out if you don’t perform,” he said. “It’s the things that we don’t incentivize, like preservation of riparian zones, that we should perhaps be incentivizing with our limited resources.”

The Mesoamerican Barrier Reef System offers an example of the interconnectedness of agriculture effluent and environmental harm. Pollutants, particularly sediment and nutrients carried downstream from plantations to the Caribbean Sea, have the equivalent effect of a 10-degree temperature change, bleaching the coral reefs.

Impacts that are acceptable with 6.7 billion people will not be with 9 billion, Matlock concluded. If management happens only to things that are measured, and not everything can be measured, which metrics are important and how can they be incentivized? “We have to shift our thinking from maximizing any one variable or metric to optimizing several key ones.”

### Agricultural Water: Challenges and Opportunities for Africa

**Elijah Phiri, University of Zambia**

Opportunities exist to increase African agricultural productivity, despite many grave challenges, Elijah Phiri said. He described the Comprehensive Africa Agriculture Development Programme (CAADP), an African-led program designed to help countries achieve economic growth through agricultural development.

African countries give little attention to investing in institutions, human capital or required skills, Phiri said. And few have sound strategic policies, or the legal and regulatory framework to manage water resources efficiently. In addition, many countries share river basins, creating a



Elijah Phiri

significant hurdle to effective water management and a potentially serious source of conflict between nations.

To overcome these challenges, CAADP works at the political level to improve policies, capacities and investment. The program is implemented under the African Union program New Partnership for Africa's Development.

“This has come from a collective desire to see a real impact on the development agenda in terms of food security, poverty alleviation. ... There has been a recognition of a requirement for more than just new money but also a radical rethinking of how we do business,” Phiri said.

CAADP provides a framework to enable countries to achieve economic development and the U.N.'s Millennium Development Goals through an agricultural agenda to increase the annual growth rate of agricultural productivity by 6 percent. To achieve that goal, each country has agreed to increase public allocation for agriculture from a typical 3 percent to 10 percent, considered the critical minimum level, Phiri said.

CAADP has identified four major intervention areas, or CAADP pillars, to address agricultural production in Africa. They are:

- Extending the area under sustainable land management and reliable water control systems.
- Improving rural infrastructure and trade-related capacities for market access.
- Increasing food security, reducing hunger and improving responses to food supply emergencies.
- Improving agricultural research and technology dissemination and adoption.

*“There has been a recognition of a requirement for more than just new money, but also a radical rethinking of how we do business.”*

The pillars have a framework to guide member countries in their agricultural development plans and priorities. Each framework provides quality assurance, support in designing investment programs and analytical tools for monitoring and evaluation, stakeholder analysis and institutional capacity assessment, among other key functions.

Each CAADP pillar has a list of policy priorities. The land management and water control pillar, spearheaded in part by the University of Zambia (UNZA), also deals with soil fertility management and rainfed and irrigation water issues. Land policies are challenged by communal land

rights in some areas, which make it difficult to use the land as collateral for investment. Phiri and his UNZA colleagues have created a land policy document at the continent level to overcome such obstacles. Other problems they are addressing include soil and land degradation.

CAADP's process engages stakeholders at many stages during the program development process by creating a common understanding for moving forward, conducting evidence-based analyses, designing and developing programs and alliances, and reassessing priorities and programs.

The process is elaborate with many players involved, Phiri said, but it is widely recognized as a principal framework or reference for agricultural development intervention in Africa. There is greater momentum to act together to increase economic growth through agriculture and a renewed interest in investing in Africa.

# Human Dimensions of Water for Food Production

## Agricultural Productivity in Developing Countries: The World Food Equation and Food Security

Lilyan Fulginiti and Richard Perrin, University of Nebraska–Lincoln

After an age of abundance, feeding people in the future will require 70 percent more food production by 2050, equivalent to about a 1.3 percent annual growth rate, Richard Perrin said. His colleague, Lilyan Fulginiti, presented research about how well various countries and continents are doing to get there.



Lilyan Fulginiti

Productivity often is considered in terms of yield per acre, a single-factor measurement. In contrast, “agricultural productivity” factors inputs into the equation. After subtracting growth rates of inputs from outputs using total factor productivity (TFP) measurements, “there is something left over that is not explained by traditional inputs,” Fulginiti said, “and that’s what we call innovation and efficiency in the use of resources.” TFP growth is an indicator of a country’s ability to innovate and make gains beyond those made by adding more resources, such as water or land.

In the U.S., TFP growth rates are declining, as are actual yields, causing concern. Is the same

slowdown occurring in developing countries as well? Fulginiti asked. To answer that question, she looked at TFP growth rates in Sub-Saharan Africa, South America, Central America and China.

Of the 46 countries examined in Sub-Saharan Africa between 1961 and 2006, both traditional outputs and inputs, such as fertilizer, had increased. Eleven countries, led by Mauritius, South Africa and Nigeria, also have reached or exceeded the 1.3 percent TFP growth rate needed to sustain future food needs, while the growth rate in six countries had contracted. Differences between countries stem from colonial heritage and years since independence, amount of irrigation and the number of drought events.

Overall African TFP growth rates from 1990 to 2006 were 1.09 percent. “Even though it’s not at 1.3, at least the tendency seems to be going the right direction,” Fulginiti said. “It’s not such bad news here ... They are approaching the technologies and the level of efficiency that we have in developed countries.”

In South America, countries are experiencing rapid growth in inputs and production, particularly in the Southern Cone, where Brazil and Argentina account for 85 percent of output. The South American countries achieved TFP growth over 1.3 percent between 1990 and 2006, with the overall average at 2.5 percent. “For South America, we also see very big increases or solid and healthy productivity growth up to now,” Fulginiti said.

The factors affecting rate differences in South American countries included land quality, life expectancy (a proxy used for health and education), public inputs, such as telephone lines and agricultural research, and political rights and civil liberties. Trading density ratio, however, did not affect agricultural productivity.

In Central America and the Caribbean, average TFP growth has increased since 1977, and both regions have reached 1.5 percent since 1990, led by Cuba.

Fulginiti also looked at China to determine if the country's fast growth was due to increasing resource use or was based on innovation. Beginning in the 1990s, China's agricultural production dropped significantly, but following reforms in 1998, has been increasing for the past decade and now averages 2.3 percent. The results suggest that yield productivity

gains have shifted from increasing inputs to a more efficient use of resources.

"It seems that developing countries are not slowing down," Fulginiti concluded. "They might be ... achieving or closing the gap with the developed countries." To continue this positive trend, countries need more resources, new technologies and more investment in agricultural research, she said.

Fulginiti also emphasized the need to focus on policy and trade reform and on investments in women's education, health and infrastructure. She suggested focusing on incentive-compatible policies. "These are incentives not only compatible from a private point of view," Fulginiti said, "but it's an incentive compatible from a social point of view where we do take into account not only private costs, but private social costs and social benefits."

## Managing in a World of Ever Increasing Water Scarcity: Lessons from Australia

**Mike Young**, University of Adelaide, Australia

Australia's water management reforms of the past 20 years have led to significant innovations and allowed for rapid adjustments in times of drought, offering a model for other countries, Mike Young said.

An important building block for reform was redefining water rights. Water is not allocated in Australia based on seniority as in many countries, but on the number of shares held within pools.



Mike Young

# Human Dimensions of Water for Food Production

Allocations, made in proportion to the amount of water available for each pool, are metered and made twice a month to more quickly respond to changing conditions.

Trading water shares, transacted through water accounts set up much like bank accounts, also has played a major role in creating incentives for innovating and in allowing for rapid adjustments.

Water shares can be traded quickly and easily to adjust to water scarcity conditions so that, for example, water is used where it is needed most and annual crops can be idled until water conditions improve. The dramatic increase in water trading also has led to improvements in inefficient water irrigation management districts.

Under Australia's system, governments decide allocations and rules, and individual users hold trading rights, removing the need for courts and lawyers and expediting the ability to adjust to water conditions. In addition, irrigation water districts hold entitlements to distribution losses, giving them an incentive to conserve water.

“The revolutions that have occurred since we've done this have been massive in terms of actual improvement in productivity,” Young said of the reforms. Rice production, for example, has increased significantly while water use has gone down dramatically.

## Revolutionizing Management Efficiency

A key component in revolutionizing water

management efficiency was to turn the once government-run water supply systems over to farmers. The farmer-owned, share-based systems have lowered costs while doubling the value of

their water assets every four and a half years.

“It's been a very profitable period and a very successful financial experiment,” Young said.

Australia learned several important lessons along the way. The country's

severe droughts, for example, demonstrated that changes don't necessarily occur gradually but in steps. A significant drop may signify a new average around which plans should be made.

In addition, when water resources are reduced by half, water available for agricultural use is reduced by three-quarters because river flows must be maintained. “Unless you've got water in your river, you can't take water out,” Young said. “The first thing you've got to do is recognize the fixed costs that are in the system. Understanding that is very challenging.”

The innovations resulting from reforms have improved water efficiency and yields. Many farmers now use an automated water delivery system and soil probes to measure moisture levels. The resulting water savings have been massive and have allowed farmers to maintain production with very little water, Young said, adding that “it came because we decided to search for innovation and run bottom-up processes rather than top-down planned processes. And that's been really important.”

*“The revolutions that have occurred since we've [made reforms] have been massive in terms of actual improvement in productivity.”*

Despite the reform's success, Australia made mistakes, such as not accounting for groundwater resources and not allocating enough water to the environment, requiring the government to buy back shares. The country is continuing to experiment with additional reforms.

Young urged other countries to rethink current practices and institutional arrangements. His

advice: Consider a system based on shares, not seniority; define entitlements to savings early to let the system start to evolve; decide who, besides politicians, is going to be responsible for the environment; and allow integration to come from a bottom-up process rather than top-down to facilitate innovations and adjustments to a rapidly changing world.

## Questions and Answers

**Audience question:** *Political stability is required for private investment. What signals should investors look for in Africa to know when to invest?*

Elijah Phiri said he believes that Africa is more conducive for investment now than 20 years or even 10 years ago because of growing acknowledgement that democracy and investment must be part of Africa's development.

**Audience question:** *Does the 1.3 percent growth rate through 2050 reflect total demand from the 1 billion undernourished people becoming market participants in the future?*

Richard Perrin responded that the 1.3 percent growth rate figure comes from the International Food Policy and Research Institute and takes income growth into account in the poorest countries, but he did not know the specific figures. Lilyan Fulginiti added that the 1.3 percent figure keeps the income distribution constant but calculates a rise in everyone's income.

**Audience question:** *In Australia, what happened to farmers who lost service from irrigation districts because their farms were inefficient in terms of water delivery?*

Farmers decide to sell water; it is not forced, Mike Young said. He described a situation in which farmers in Australia's least efficient irrigation system – a place where people were struggling – took control, invented water trading and turned their district around. Many people left but seem to be thriving in other businesses. "It looks very frightening," Young said. "People start leaving, but we find it very, very hard to find concrete examples of people who are worse off that otherwise wouldn't have been in strife anyway."

**Audience question:** *What was present in Australia that was different from U.S. water rights that allowed Australia to create a share-based system?*

Young described three situations: First, long before reform, Australia opted not to follow America's individual seniority ranking,

## Human Dimensions of Water for Food Production



but instead established ranking based on seniority pools. Second, in the early stages, Australia guaranteed volumes to those with higher priority. And third, strong political leadership in the early 1990s forced states to make water rights tradable or they were severely fined.

**Moderator Raymond Supalla:** *How should we allocate resources between increasing productivity with existing resources and bringing additional land and water resources into production in an environmentally sustainable way?*

Perrin responded that because water is a public good it must be handled through collective action, not the market. He said he believes the solution is to foster vigorous experimentation from bottom-up choices for community control over resources. Success will require consensus at local levels for regulating, controlling, sharing and monitoring water resources.

Phiri stressed that planning processes must be evidence-based and cooperative. Identifying

best practices provides the facts for planning investments and programs. In addition, obtaining political buy-in and general consensus from all stakeholders, including farmers, is necessary.

Young discussed the importance of institutional design. Australia now understands the importance of planning at different scales rather than trying to manage entire basins from the bottom up so local problems can be resolved without involving the entire basin.

Fulginiti said she believes greater investment in agricultural research is needed. Because agricultural research is a public good, the market fails to provide appropriate incentives to invest, though the rate of return in agricultural research is extremely high. Institutional reform is needed to ensure the necessary investments.

**Audience question:** *How has Australia's trade from inefficient to more efficient producers affected consumptive water use?*

Australia made significant mistakes that severely damaged the environment and cost the government billions to correct, Young conceded. Over-allocations resulted from not understanding how much return flows were needed, and governments and industry were slow to respond. However, much good also occurred, including people leaving environmentally sensitive areas because of low productivity. The government is trying to rectify the environmental problems.

**Audience question:** *Given that only 17 percent of Zambia's arable land is cultivated, what is Elijah Phiri's view of land expansion?*

Zambia, unlike several other African countries, has much land available for cultivation, Phiri said. The issue for Zambia and the rest of the continent is lack of investment in industry and infrastructure to support agricultural production.

**Audience question:** *How does Australia's system deal with trade impacts to third parties?*

Richards described rules and regulations established to pressure irrigation districts, particularly badly managed districts, into becoming efficient and innovative. The environment also was negatively affected and is just now being corrected. Communities feared capital flight, but in fact more jobs were created as people sold water and invested in farm upgrades.

**Audience question:** *In Australia, to what extent has meeting environmental, recreational and similar water uses been a problem? How are they provided for in a market system?*

Massive drought made Australia's environmental plans inappropriate, Richards said. The government suspended the plans, and now a commonwealth holds a water entitlement for the environment. "We're now going into the market, buying back water for the environment because our allocation systems were flawed."

**Panelist Fulginiti:** *Was Australia's prime minister who introduced the reforms re-elected?*

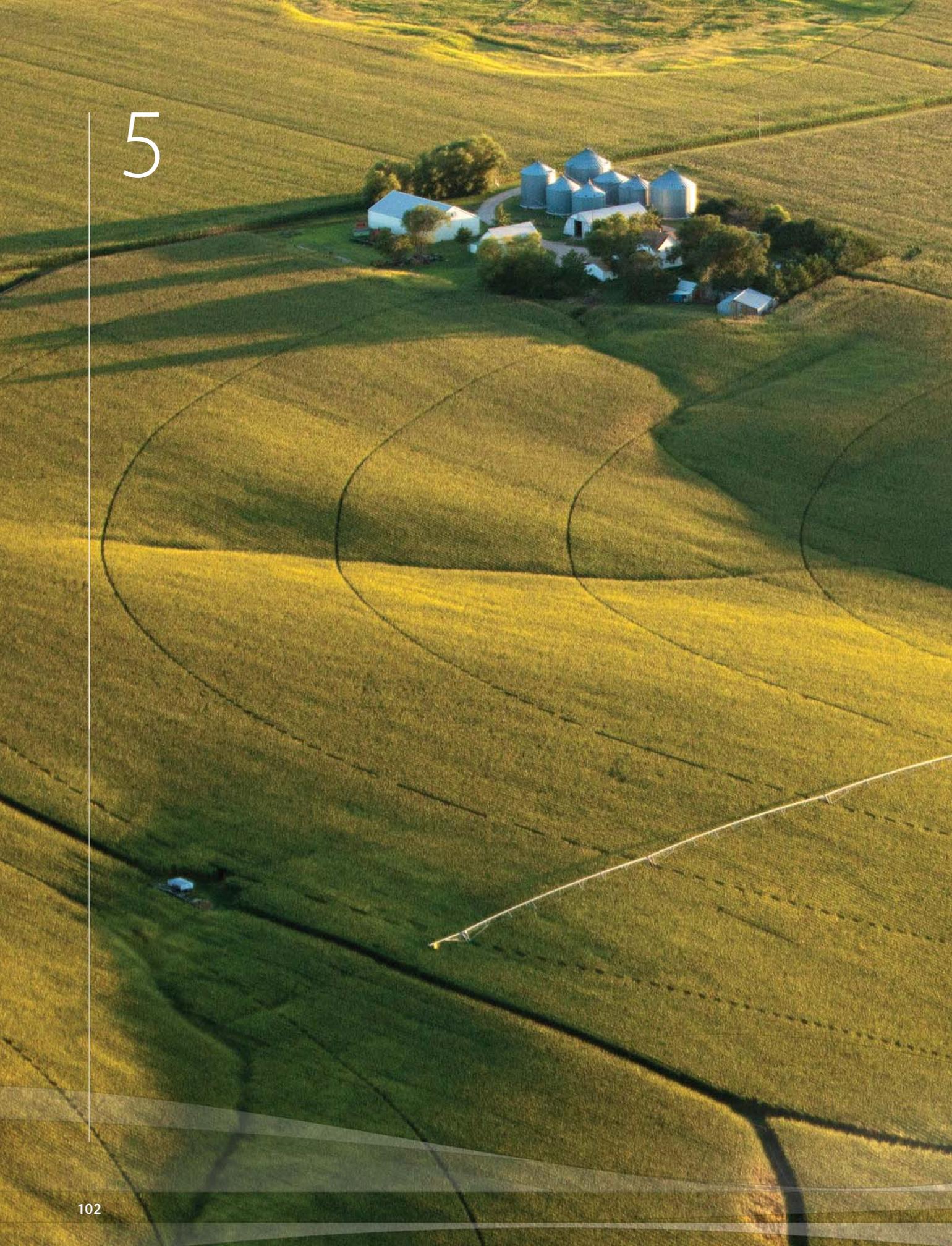
Yes, but subsequently lost, Richards said, adding that water reform has bipartisan support in Australia, although much arguing over details and game playing occurs. Many Australians consider the reforms a disaster, he said, and the country has made many mistakes, "but the final shape of what is starting to emerge, I think all Australians are very proud of."

**Moderator Supalla:** *Final comments?*

Phiri emphasized that Africa has established institutions and policies that make investing safe. For example, in Zambia, investors can back out at any time without restrictions. Eighteen countries involved in CAADP are establishing agricultural priorities and strategies and beginning to develop plans, which will facilitate investing. Investment and support to strengthen capacity are much needed, he added. A network of institutions working together would help tackle the mammoth task.

Fulginiti stressed the need for institutional reforms that include incentives compatible with social benefits and returns, not just private benefits.

5





# TECHNOLOGIES AND ADVANCES IN WATER MANAGEMENT

# Technologies and Advances in Water Management

## Panel

### **Suat Irmak**

Associate Professor of Biological Systems Engineering,  
University of Nebraska–Lincoln

### **M. Can Vuran**

Assistant Professor of Computer Science and Engineering,  
University of Nebraska–Lincoln

### **Steven R. Evett**

Research Soil Scientist, USDA-Agricultural Research Service  
Conservation and Production Research Laboratory

### **Gary Hergert, Moderator**

Professor of Agronomy and Horticulture, University of Nebraska–Lincoln

*The session focused on technological advances that enable producers to better manage limited water resources. Topics included research on models that measure crop stress and evapotranspiration, development of wireless underground sensor networks to measure soil moisture and other conditions, and advancements in irrigation technology since the early 1960s. Each panelist gave an overview of his subject area and the panel then responded to audience questions.*



From left: Steven R. Evett, M. Can Vuran, Suat Irmak and Gary Hergert

## Highlights of Research and Educational Programs Related to Agricultural Water Management in Nebraska

### Suat Irmak, University of Nebraska–Lincoln

Farmers are challenged to use water more efficiently while maximizing net return, Suat Irmak said. Researchers at the University of Nebraska–Lincoln (UNL) are investigating ways to improve agricultural practices and minimize water loss.

Center pivot irrigation research is designed to measure and understand crop response to water and chemigation under limited and full irrigation settings with the goal of determining how much farmers can reduce irrigation while maintaining high yields.

Irrigation treatments investigated range from dryland conditions to 50 percent irrigated to fully irrigated, and measurements include biomass production, kernel weight and other grain quality parameters. Other research addresses the effect of irrigation frequency on crop yield, water use efficiency and soil evaporation for corn under subsurface drip irrigation. Four years of results indicate that, in most cases, high-frequency irrigation leads to higher yields than low- or medium-frequency irrigation.

Additional research on crop water stress aims to determine, in part, how much stress the crop can withstand without a reduction in economical yields. A crop water stress index is determined from continuous canopy temperature monitoring using infrared thermometers from a few days after emergence to physiological maturity, coupled with microclimate variables, such as temperature and humidity.



Suat Irmak

Irmak and his colleagues also are improving models to separate evapotranspiration (ET) into evaporation and transpiration. By obtaining field measurements of stomatal conductance, researchers can develop a model to estimate transpiration. Such measures could be used to better analyze water use efficiency and other agricultural production indices. “We can do a pretty good job estimating or measuring soil moisture, rainfall or snowfall, but I think we have a long way to go to accurately quantify evapotranspiration,” Irmak said.

Irmak established the Nebraska Water and Energy Flux Measurement, Modeling and Research Network to measure ET for a variety of vegetative surfaces, including irrigated and rainfed crops and grasslands, crops under different conservation practices and invasive species. Twelve network instruments have been collecting data continuously throughout Nebraska for several years. One finding showed that

# Technologies and Advances in Water Management



Sunflower field

disk-tilled fields averaged 7 percent higher ET rates than no-till fields during the past 18 months.

Other research, led by UNL biologist Ayse Irmak, estimates ET using satellite remote sensing. By integrating information algorithms, such as surface temperature and net radiation, ET mass for large areas can be estimated. “I see great potential for this technology to be used for water resources management and assessment,” Suat Irmak said.

Another study investigates the effect of climate change variables, such as air temperature and solar radiation, on agricultural functions, particularly ET rates. Analyzing historical data (going back to 1893 at one site), Irmak found a slight decrease in ET rates, despite slight increases in air temperature.

Passing research results to farmers, crop consultants and other users is critical, Irmak said. Without adequate communication, conserving water resources – the ultimate

objective – cannot be achieved. That’s why Irmak and his colleagues established the Nebraska Agricultural Water Management Demonstration Network to integrate research and the work of UNL Extension.

The network’s goals are to transfer high-quality research to farmers, increase water use efficiency, reduce input and energy use, and improve management practices. The network also brings together researchers, growers and others for collaboration and learning. A website and on-site demonstrations give farmers useful tools and technologies.

The project began in 2005 with 15 Nebraska farmers and now has 400 members. Participating farmers are saving about 2 inches of water per growing season. The network comprises about 340,000 acres and is growing. “The network is an excellent example of university, farmers and state agency personnel coming together ... to improve the productivity of agriculture,” Irmak concluded.

## Wireless Underground Sensor Networks: A New Perspective for Automated Water Management

**M. Can Vuran**, University of Nebraska–Lincoln

Wireless sensor networks are one of 10 technologies that will change the world, according to *MIT Technology Review*. M. Can Vuran is taking the technology a step further by developing wireless underground sensor networks to gather information about the soil, which he believes could revolutionize agriculture.

A wireless sensor network consists of autonomous sensor nodes that gather environmental information and relay it wirelessly. The nodes are essentially tiny computers with limited processing capabilities and memory. They are powered by only two AA batteries and are inexpensive to produce.



M. Can Vuran

Wireless sensor networks already play a large role in energy efficiency, Vuran said. His goal is to apply the technology to precision agriculture using nodes buried in the field. He is creating sensors that gather real-time information from the soil and crop conditions and transmit the information to personal computers or cell

phones, enabling farmers to make immediate, informed decisions. “We want to let the soil tell us what to do,” Vuran said. “And we want to achieve a complete autonomy on the fields. We basically want farmers that are walking around their farms with iPads.”

Taking low-power wireless sensor networks below ground, however, is a new frontier with many challenges. Operational systems that last one or two years and that communicate through the soil have long been considered infeasible. But the low cost of each node may improve the feasibility of a high density of sensor nodes that communicate over a shorter distance through a relay network.

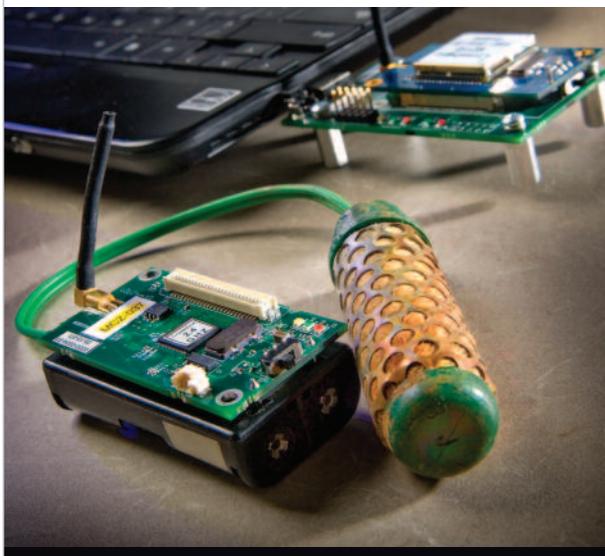
Vuran’s experiments using off-the-shelf sensor nodes demonstrated that underground communication quality is highly stable over time, but soil moisture is the most important parameter affecting quality. A 9 percent increase in soil moisture resulted in a decrease in channel quality of 20 decibels per milliwatt. Increasing transmission power, however, minimizes the adverse effects of moisture. Therefore, it is necessary to establish environment-aware networking, in which the environmental information is exploited to provide networking solutions that can withstand the effects of the weather and other changes.

Based on these empirical studies, Vuran and his colleagues developed the Soil Subsurface Wireless Communication channel model. Three signals are

## Technologies and Advances in Water Management

involved in the network: direct waves, reflected waves and lateral waves, which propagate through the air-to-soil boundary before reaching the receiver, increasing reliability. “We’re exploiting this third component,” Vuran said. “We can actually improve the communication range that will lead to the realization of underground sensor networks.”

The team also experimented with above-ground-to-underground communication, important for node maintenance. Researchers discovered that sending a 400-megahertz signal from the air to the soil requires an antenna tailored to a 1-gigahertz signal in the soil because of the change in wavelength. Using the ultra-wideband antenna significantly increased the range for above-ground-to-underground communication, and vice versa.



Wireless sensor and transmitter

*“We can actually improve the communication range that will lead to the realization of underground sensor networks.”*

To test the system in the field, Vuran deployed eight underground nodes, buried 40 centimeters deep (the depth at which nodes are considered safe from agricultural machinery), and an above-ground node connected to a center pivot system. The system achieved nearly 100 percent communication reliability as the center pivot circled the field. The corn canopy and a 6.1 percent increase in volumetric water content each increased attenuation 3 decibels.

Soil irregularities appear to cause high space-time variability of signal strength. Combating the problem will require developing adaptive real-time protocols that provide multiple levels of temporal guarantees, Vuran said. For example, irrigation and rain can affect communication within hours, while soil moisture changes may impact communication over days. “We basically have information about the models that have been developed for these agricultural phenomena,” he said. “Already we can tie this information with developing real-time protocols that can combat these effects and can still provide information despite the adverse effects in communication.”

Many research challenges remain, but Vuran’s study has provided a proof of concept of the ability to deliver autonomous agricultural solutions by feeding environmental information collected underground to above-ground devices.

## Trends in Crop Water Productivity Enhancement: Why the New Green Revolution Must Be Blue-Green

**Steven R. Evett**, USDA-Agricultural Research Service

Irrigation has been an essential component of a global strategy for increasing yields to feed a growing world population. Steven R. Evett described new technology and future trends in irrigation in the U.S. and around the world.



Steven R. Evett

Despite a booming global population, worldwide nutrition has improved largely because of increasing yields. Irrigation and the synergistic effect between irrigation and nitrogen in advanced varieties have played large roles.

Worldwide, irrigation has doubled since 1960, but in many important regions, irrigators have reached the limit of water availability. South Asia, the Middle East and North Africa are extracting half of the available water for human resources – an untenable situation, Evett said. “We need greater crop-water productivity in order to deal with this situation. Yield growth in resource-limited regions is going to be critical, but it depends on technology development,” he said.

In the U.S., irrigation has allowed production to more than double since 1960. At the same time, cultivated land and the amount of water applied per acre have decreased because vapor pressure deficits (VPDs) decrease from west to east. Lower VPDs indicate higher moisture levels on the plant surface; therefore, less irrigation is needed. Studies also have shown that irrigation increases crop-water productivity; as yield goes up, water use efficiency goes up.

Advances in irrigation technology and management have been critical. Pressurized irrigation decreases conveyance loss and improves the ability to manage irrigation systems. By 2000, about half of U.S. irrigated areas were served by pressurized irrigation, but more is needed. Other advances include weather station networks coupled with irrigation scheduling systems, improvements in crop-water use predictions, and scheme- and region-wide water demand predictions using satellite and aerial data.

Evett discussed examples from his work in Jordan and Uzbekistan. Jordan’s irrigated area is small but economically and socially critical. Irrigation is 95 percent pressurized and 30 percent of the irrigated area is covered by plastic houses, increasing productivity to high levels. A new weather station network, text messaging to farmers and a weighing lysimeter to determine crop-cover effect on water use are improving irrigation scheduling. In addition, the Middle East Regional Irrigation Management Information

# Technologies and Advances in Water Management

System has achieved successes in conducting research, establishing technological infrastructure and developing human resources.

Uzbekistan, in contrast, has inefficient surface irrigation. In field studies using drip irrigation, corn yields increased only slightly, but 35 to 43 percent of irrigation water was saved and crop-water productivity increased 64 to 78 percent. Cotton yields increased about 22 percent and crop-water productivity increased 76 to 103 percent.

Evelt described the results of using the Temperature-Time Threshold method of automated irrigation for controlling water use efficiency in Texas. The method was successfully automated for drip and center pivot irrigation systems. Water use efficiency was controllable, and yields were equal to or larger than the most accurate manual irrigation scheduling method.

New technology is allowing mapping of yield potential so farmers can abandon fields identified to have low yield potential. If the technology sends the feedback information to the irrigation system, areas that are diseased or dying can be excluded from irrigation.

Despite these advances, many constraints to improving agricultural water use efficiency exist. Economic, regulatory and social impacts, such as water pricing, technological availability, land tenure issues and fair markets, are critically important and must be addressed in many regions.

The picture is always changing, Evelt concluded. “We have to keep expanding our thinking about how we can improve crop-water productivity and how that can tie into profitability for farmers. Because if it doesn’t tie in with profitability, it’s not going to happen in the end.”



Center pivot irrigation in Saudi Arabia

## Questions and Answers

**Audience question:** *What would Suat Irmak consider the major challenges and barriers for adoption of no-till agriculture in Nebraska?*

Irmak said the major challenges are the unknown factors, such as how yield changes with no-till, the amount of water saved and the effects of various parameters, such as soil type and management practices. In addition, no-till increases weed and disease challenges, which have yet to be addressed.

**Audience question:** *What soil texture and clay types were involved in M. Can Vuran's field soil experiments? How do soil type and texture affect wireless underground sensor networks?*

Although clay soil is dry, clay particles have significantly higher attenuation because they hold moisture, Vuran said. While soil type is important, it cannot yet be modeled well. His model incorporates existing models that capture some soil properties. Before deploying an underground sensor network, site-specific studies will be necessary to understand soil properties.

Irmak added that the soil texture at some of Vuran's field experiments is 20 percent clay, 14 percent sand, 64 percent silt and 2 percent organic matter.

**Audience question:** *What is the underground nodes' battery life?*

Vuran said the lifespan of the two AA batteries that power the nodes depends on the information gathered and how frequently it is sent. The nodes

consume little power when asleep, so minimizing information exchange will prolong the communication lifetime to one or two years.

**Audience question:** *What is the role and adoption of partial-root drying in irrigation management?*

Steven R. Evett replied that he had not done experiments on partial-root drying. Evidence suggests that it can improve plant efficiency, and Australian vintners believe it improves grapes. However, Evett said he doubts that efficacy translates to corn.

**Audience question:** *What is the difference between conductances at night compared to daytime?*

Irmak responded that UNL has a unique dataset to measure stomatal resistance. Resistance increases significantly at night; therefore, conductance decreases. At night, corn measures from 300 seconds to 3,000 seconds per meter, while daytime measures are 30 seconds to 300 seconds per meter.

Although long doubted, transpiration does occur at night. Evett added that in the Texas Panhandle, 20 percent of total evapotranspiration (ET) occurs at night. He believes it comes from transpiration, not soil evaporation.

**Audience question:** *Given the closure errors and footprint uncertainty with eddy covariance, how is Irmak correcting eddy covariance flux to get true ET?*

# Technologies and Advances in Water Management

Irmak said he uses the Bowen ratio-energy balance system, which doesn't have closure errors.

In the Jordan Valley, Evett has collected eddy covariance data, which underestimate ET by 30 percent and are dangerously misleading in places where scientists don't have direct measurements from a weighing lysimeter.



Center pivot circles along the Columbia River

**Audience question:** *Is there utility in deficit-irrigation schemes based on growth state? If so, is there research available using that scheme?*

The data exist, and Irmak suggested that Tom Trout of USDA-ARS in Fort Collins, Colo., would have extensive data.

Evett said the Food and Agriculture Organization (FAO) recently released a water-productivity model called AquaCrop that he ran on cotton for both full and deficit irrigation to get accurate results. *Agronomy Journal* published those results about two years ago. After the root zone is established, deficit irrigation during one stage followed by full water in the next is a viable option.

Irmak said FAO publication No. 33 is an excellent resource that researchers have relied on for decades, but a revision is needed to account for advances made in the past 30 years.

**Audience question:** *What is Evett's opinion about the new soil moisture sensors that can be interrogated down to the hour, etc.? What would it take to schedule irrigations that way?*

Evett based manual irrigations on neutron probes, which is not a tool farmers can use. Studies have concluded that electronic sensors designed to replace neutron probes do not work well enough for research or irrigation scheduling. Soil bulk electrical conductivity changes with water and clay content and is unpredictable *a priori*. Evett described fundamental problems with capacitance sensors and microstructural soil influences that create spatial variations. "What that means in terms of actually using these things is that we can't," Evett said. "We can't rely on them because we don't know *a priori* where to put them."

**Audience question:** *If crop prices are high and water is scarce, what technologies will producers adopt to adjust?*

Irmak said he believes increasing productivity in that setting would require integrating advanced irrigation management technology with other technologies, such as soil management and enhanced drought-tolerant crops.

Evett said farmers in the Texas Panhandle and southern Kansas and Colorado are facing that situation. Rather than buying new irrigation

systems, farmers compensate by switching from low-value crops to corn. However, center pivot irrigation is used for more than 75 percent of the land because it's more efficient. Drip irrigation also is becoming more widely adopted as a way to eke out more production for the same amount of water.

Irmak stressed that optimizing crop production with available water is extremely important. Robust tools are available to optimize production under deficit irrigation settings.

Vuran said as food prices increase and water becomes scarce, farmers have greater incentive to adopt newer technologies. Precision agricultural techniques and integration of information technology into agriculture would be important advances.



No-till field with an emerging corn seedling

**Audience question:** *To what extent should we consider redesigning plant root systems, particularly for no-till management?*

Evelt responded that roots are critically important to water uptake. For example, soil type directly affects how well crops take up water. Understanding how specific crops fare in different soil types would help farmers. Roots also are important in plant breeding because stronger roots that reach deeper into the soil will provide more water for the plant.

**Moderator Gary Hergert:** *Closing comments?*

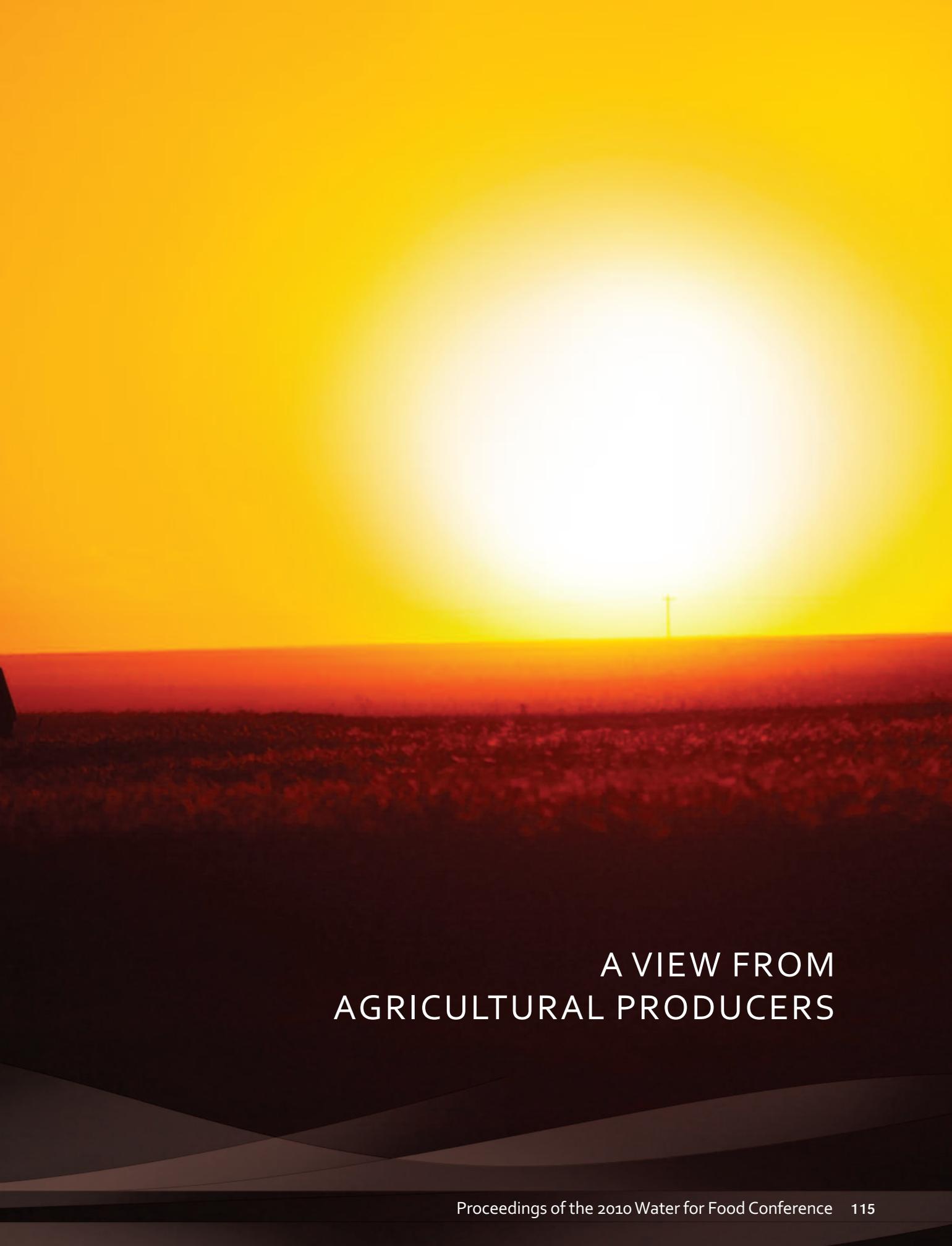
Evelt described the changes he has observed since he began working in Africa in the 1970s. The world is becoming smaller, he said. “We shouldn’t be bound by the perceptions of the agricultural system we see today. ... We shouldn’t be bound by our expectations and our experiences of the past.”

Vuran stressed the importance of interdisciplinary research to tackle complex problems. Solutions already exist that are directly applicable to some of these problems, and combining multiple disciplines will lead to additional solutions.

Irmak emphasized the need to invest in agricultural research, education and information transfer. To open the door for cooperation with international partners and researchers, his presentation highlighted some of UNL’s capabilities and experiences. Much remains to be understood about these complex problems, and he invited researchers to collaborate with UNL to address the issues facing irrigated agriculture in the U.S. and around the world.

# 6





# A VIEW FROM AGRICULTURAL PRODUCERS

## A View from Agricultural Producers

### Panel

**Martin Pasman**

Producer, Argentina

**Keith Olsen**

Producer and President, Nebraska Farm Bureau

**Roric R. Paulman**

Producer, Paulman Farms, Nebraska

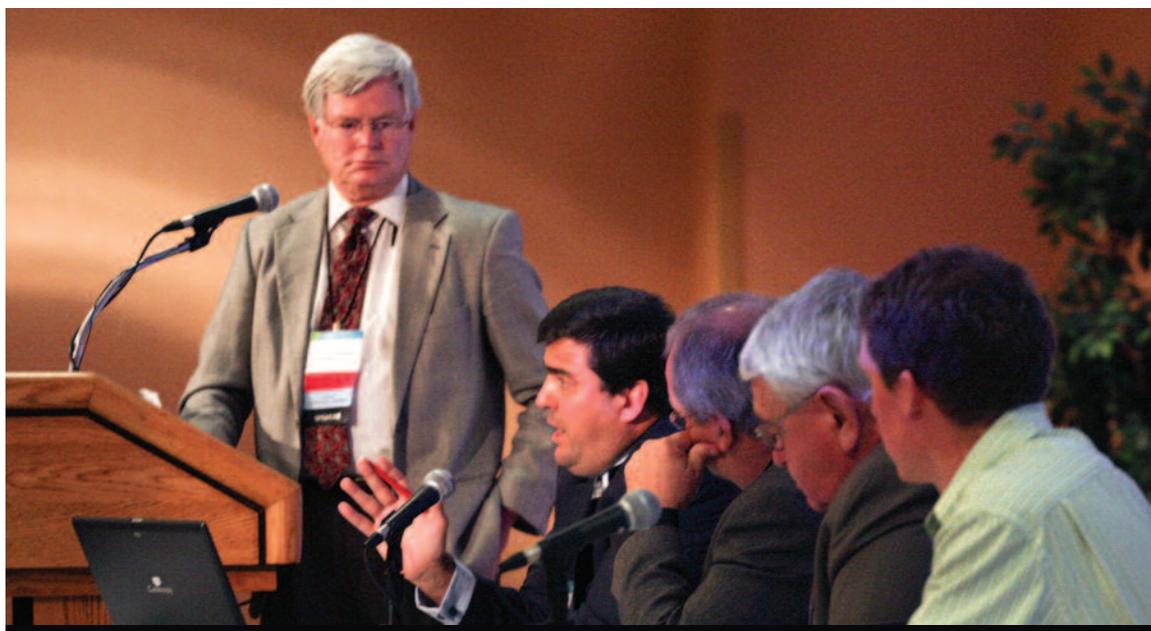
**Aaron Madison**

Producer, Madison Farms, Oregon

**Mark Gustafson, Moderator**

Coordinator, Nebraska Rural Initiative

*The panel provided the viewpoints of large-scale agricultural producers, whose operations range from a 20,000-hectare operation in Brazil to irrigated and rainfed farms in Nebraska and Oregon. The panelists provided brief overviews of their farming operations and then responded to audience questions.*



From left: Mark Gustafson, Martin Pasman, Roric R. Paulman, Keith Olsen and Aaron Madison

## Rainfed and Irrigated Production in Argentina

### Martin Pasman, Producer, Argentina

Martin Pasman, an Argentine agronomist with a master's degree in business administration, began his career as a consultant to farmers and has experience in Argentina, Uruguay, Paraguay and Brazil, where he was instrumental in helping to develop 80,000 hectares in the western part of the Cerrado area. His farming experience stems from his family's farms, located in five areas of Argentina. Most are rainfed, but one area receives less than 500 millimeters of rain annually. Pasman also runs an irrigation business serving 80 percent of the Argentine market, giving him vast experience in developing irrigated land.

Argentina is the second-largest South American country after Brazil and is one-third the size of the U.S. One-third of Argentina receives more than 800 millimeters of rain and depends upon rainfed agriculture, while the majority receives less than 800 millimeters. Argentina cultivates 30 million hectares per year, of which 2.2 million are irrigated. Total production output is 90 million metric tons, and about 70 percent of farmers in Argentina practice no-till agriculture.

Pasman's family came to Argentina from the U.S. around 1825, when it was primarily cattle country. His family brought the first Aberdeen Angus bull to Argentina and also helped develop agriculture. In the 1970s, the family farmed 6,000 hectares, of which only 500 were used for crops, yielding 3.5 tons of corn per hectare and 1.5 tons of wheat per hectare. They plowed the land and used few herbicides and no

fertilizers. The majority of the land was used to raise 3,000 head of cattle, which were finished in natural pastures.



Martin Pasman

Today, the family's farm operation has expanded to 20,000 hectares, 15,000 of them used for agriculture. In the low-productivity land, they also manage 9,000 head of cattle in cow-calf operations, finishing the animals in American-style feedlots. In rainfed fields, the Pasmans produce 8 tons of corn per hectare and 3 tons of wheat; under irrigation, they get 12 tons of corn and 6 tons of wheat. The most important crop, however, is soybeans. They also grow potatoes, corn and sunflower seeds for Monsanto Company. The farm uses 42 pivots to irrigate 4,000 hectares, and about 80 percent of the farm is double-cropped: wheat plus soybeans, seed corn plus soybeans, potato plus corn. Argentina uses a huge amount of herbicides and genetically modified crops, Pasman said, adding that his farm was one of the first to produce Roundup Ready® soybean seeds in 1994.

## A View from Agricultural Producers

“The cornerstone of our production technology is no-till,” Pasman said, a technique used on the entire farm except the potato fields, which follow a rotation of one year of potatoes followed by three years of no-till. A corn crop follows the potato harvest in the same year.

No-till improves water infiltration and water retention and reduces evaporation because the previous crops’ residue minimizes runoff and allows the soil to retain more water. No-till also reduces erosion risk and increases organic matter,

improving oxidation and carbon circulation in the soil. It improves soil fertility, increases productivity and sustainability, and allows farming in difficult soils, particularly shallow soils of 3 inches.

No-till uses less than half the water and less labor compared to conventional tillage, reducing production costs by 30 percent, Pasman concluded. “It is very important, the mix of no tillage with center pivot (irrigation) against traditional management.”

### No-till Rainfed Farming in Nebraska

**Keith Olsen, Producer; Nebraska Farm Bureau**

Keith Olsen’s family arrived in southwest Nebraska in 1923 when his grandfather, thinking he could raise corn in western Nebraska, moved west after going broke farming about 60 miles southeast of Lincoln, Neb. It turned out the land in western Nebraska was too dry for corn, so Olsen’s grandfather grew wheat until the Dust Bowl of the 1930s. The family farm survived by following University of Nebraska soil conservation advice to plant wheat every other year, letting the ground lie idle for a year to regain moisture. In 1970, Olsen returned home from college to continue the family’s traditional fallow-wheat rotation. “Little did I know how things would change,” Olsen said.

By the late 1970s, the Olsens had started using fertilizer because university tests showed the investment paid off. In 1980, the family started experimenting with eco-fallow farming. The following year, Olsen started planting milo into



Keith Olsen

wheat stubble with some success. When corn hybrids for dryland conditions were introduced, Olsen began planting corn, though delayed by a then-government policy that didn’t allow farms to change crops unless farmers were willing to operate outside the farm program. “The farm program delayed how quick I converted to a no-till operation,” Olsen said. “But we got into no-till long before GMOs (genetically modified crops) were there.”



No-till soybean field

Today, Olsen's middle son works his own operation on the farm as well. The farm receives about 19 inches of rain, but neither Olsen nor his son irrigates. Practices have changed considerably since Olsen returned to the farm. Then, farmers harvested wheat close to the ground, leaving little stubble and a windrow of straw. The next year they worked the ground bare. Rain or wind caused tremendous soil erosion. "These were two issues I wanted to change on my farm," Olsen said. "... We had to look at a different way of doing things."

He now practices no-till farming. The benefits are obvious. After a 6-inch rain, a tilled field leaves much standing water, while water quickly soaks into no-till soil, retaining moisture. Tracks between rows also conserve moisture, providing ground cover to slow wheat growth.

To prevent crop failures from droughts, such as those that occurred from 1999 to 2006, Olsen

is trying new soil management techniques. He's practicing wheat stubble management using a stripper head, a British invention that leaves straw in the field, providing ground cover for corn. Olsen uses winter wheat planted in the fall as straw for the following crop season. Another technique includes skip-row planting. Neighbors who till their ground suffer tremendous wind erosion, altering the quality of the wheat they grow, he said.

On trips to Russia and Turkey, Olsen observed farmers plowing their fields. Could they be using no-till farming? he asked. He'd like them to try. "Just because it works in southwest Nebraska on my farm doesn't mean it'll work in some other place, even in Nebraska, let alone other places in the world," Olsen said. "But I think there are opportunities to try these things."

# A View from Agricultural Producers

## Consumptive Water Use on a Nebraska Irrigated Farm

**Roric R. Paulman, Paulman Farms**

Roric R. Paulman, a self-described early adopter of technology, is a third-generation farmer who returned to the farm in 1985 to help his father during U.S. agriculture’s financial crisis. The Paulmans had cattle and hogs and irrigated land. (At the time, land cost \$300 an acre, plus another \$300 to drill a well and put up a pivot.) Six months later his father passed away. “At that time I had to decide: Am I going to take advantage of an opportunity, make this a lifestyle again, or am I going to turn tail and run?” He and his wife, a teacher, quit their jobs in Omaha, Neb., and returned to farm, teach and raise four children in western Nebraska.



Roric R. Paulman

Paulman has a keen perspective on the business of farming. In the beginning, Paulman had to rent back the family’s land from the Farm Credit Bureau. He gathered a team of people with money and an interest in agriculture, and over the years, opportunities arose to develop land and drill wells. Today, Paulman operates 5,600 irrigated acres with 45 high-capacity wells and 1,500 dryland acres.

Paulman’s farm has changed considerably. He was part of the Roundup Ready® revolution and adopted other new technologies and techniques to maintain ground cover. Twenty years ago, two pounds of Atrazine and some 2,4-D raised a good corn crop. Today, a quart or less of Roundup® or just three-eighths of an ounce of IMPACT® herbicide on 43,560 square feet does a great job. As his operation progressed, he brought experts to the farm, including agronomists. “I worked closely with anybody I could find because I didn’t have the background,” Paulman said, or the father figure to counsel him.

Over the years, Paulman experimented with a variety of techniques, including grid sampling and site-specific soil analysis. Paulman’s land ranges from the challenging sandy soil near Valentine, Neb., to highly productive sandy loams. He also handles the business end, purchasing his inputs, marketing his crops, originating his sales and maintaining his storage. His wife implemented an enterprise-analysis system that he still uses today.

Paulman has become extensively involved in water use issues and is developing a model for measuring consumptive use. Although he’s tried the recommended conservation efforts, he wanted to understand the effects. “We don’t talk about consumption, and what we’ve tried to do on the farm is identify what that consumption is,” he said.

Paulman rotates up to 11 different crops with some corn and soybeans, but primarily dry beans and popcorn. He also manages consumptive water use. His farms are in three local Natural Resources Districts, two of which are under close scrutiny for supplemental irrigation. The third is developing an integrated management plan.

Farmers also face load control. Public utilities cannot provide unlimited power anymore due to higher electricity costs and growing infrastructure stress. Because energy supplies and fuel costs on diesel wells restrict the amount of water that can be pumped, Paulman worked with the public utility to develop a remote management system that allows him to turn power on and off during peak evapotranspiration. To determine when to power off, he's established his own weather

stations and evapotranspiration processes to monitor and drive water use.

It takes 27 to 29 inches of water to bring corn crops to full production. Paulman's farm receives 18 inches of rainfall annually, but only up to 9 inches falls during the growing season, requiring 21 inches of supplemental water to produce a crop. Good management retains some soil moisture, but producers also must use less water. "After four years of being heavily involved with the water process, I don't think we talk enough about consumptive use," Paulman concluded. "Three hundred bushels of corn [per acre] is great, but in that same respect, I'm going to be asked in my area to reduce my consumption. So can I grow a crop to full capability?"

## Farming in an Oregon Critical Groundwater Area

### Aaron Madison, Madison Farms

Aaron Madison's great-grandfather started the farm in 1914 when he moved to northeastern Oregon from Iowa to take advantage of a Bureau of Reclamation irrigation project. Settling outside the reclamation project's boundary, he was unable to use the water on his 500 acres, which receives just 7 inches of rain a year. He settled on raising sheep and forage crops. In the mid-1900s, his son began growing more wheat using irrigation and dryland wheat-fallow rotations and switched to raising cattle.

Production practices have changed dramatically over the years. Irrigation, for example, began as flood irrigation. It progressed through hand lines



Aaron Madison

and wheel lines and is now predominately center pivot irrigation. The Madisons' farm has grown to 17,500 acres, with 7,200 irrigated

## A View from Agricultural Producers

acres. About 1,850 acres are dryland wheat with fallow rotation, and the rest is native rangeland. The family also raises a variety of crops to take advantage of the available water.

Because the farm is located in a designated critical groundwater area, it runs on 27 percent of the water typically allocated for irrigated crops. In the 1970s, the state of Oregon had revoked water rights to the aquifer because it had been over-appropriated and was declining. But the Madison farm is located 12 miles south of the Columbia River, a large river with flows of about 250,000 cubic feet per second in summer to a high of 500,000 cubic feet per second in the winter. For about 20 years, the family has added Class A biosolids to the rangeland to retain water and improve nutritive value, which has improved grazing productivity without irrigation – in some areas by more than 300 percent.

In the 1920s, 60 percent of the farm's production was used to feed the horses that powered the

equipment. In contrast, 7 percent of the 2007 canola crop produced enough oil to run the operation's equipment, illustrating the changes in technological efficiency over the years. Even as recently as the early 1990s, the Madisons used three combines to harvest the wheat and corn crops, a task accomplished by just one combine today.

Madison credits diversity in crops and water sources for allowing the farm to maintain profitability with such limited rainfall. Most of the farm's water comes from the Columbia River. Because summer withdrawals are not permitted in order to protect salmon runs, the Madisons take advantage of Oregon's Aquifer Storage and Recovery program, which allows them to take Columbia River water during the spring and fall and store it in the depleted aquifer until needed. "Variation and a variety of cropping and water sources and other enterprises have enabled us to maintain productivity," Madison concluded.



Soybeans

## Questions and Answers

**Moderator Mark Gustafson:** *What technologies or management systems have been important over the years for water use efficiency?*

For Martin Pasman, no-till farming, made possible by Roundup Ready® soybeans, was an important change, along with irrigation. Regulatory changes also have played a role. Argentina's heavy import taxes for equipment and inputs restricted the use of cutting-edge technology. After removing the taxes in 1990, Argentina's production has increased output from about 30 million tons to 90 million tons today.

Roric R. Paulman's first corn yield in 1985 averaged 153 bushels per acre. It required irrigation, seven hired men, 11 tractors and a harvest that took seven combines and two or three weeks. Today, using tools such as genetically modified crops (GMOs), chemigation, improved equipment and many others, Paulman can plant 60 acres of corn in an hour using an 80-foot planter, spray 150 acres in an hour and harvest using a single combine. But finding people with the knowledge needed to run the equipment is challenging, Paulman said.

Keith Olsen credits new crop technology, particularly GMOs, but said, "We've got a tremendous challenge, I think, down the road as we get concerned about crops becoming Roundup Ready® resistant." Reliable equipment has greatly reduced hours spent repairing machinery and has increased his farm's efficiency.

Means to move water efficiently also have advanced, Aaron Madison said. For example,

rather than running full irrigation, variable-frequency drive systems allow irrigation to run at 40 percent, which saves electricity. One of the Madison farm's biggest costs is electricity to carry water from the Columbia River. He also agreed with Paulman about the importance of education. "A lot of this equipment is getting a lot more technologically advanced," Madison said. "And the operators do need a more firm grasp of some of these systems, such as GPS guidance and variable-rate application."

**Moderator Gustafson:** *What advances do you foresee to keep your farm sustainable as climate change threatens?*

Madison reiterated the benefits of Oregon's Aquifer Storage and Recovery program. He's also interested in variable-rate water application technology that would allow fine-tuning irrigation to the specific water needs of different soil types within an irrigated circle.

Olsen said farmers have to understand that droughts occur, and no-till farming can minimize the impact of dry spells. He's confident that farming can adapt to changes, with continued improvements in practices and technology and flexibility in operations.

Paulman said a broader understanding of water supply is needed, from precipitation to surface water and storage capabilities in the Ogallala Aquifer. "I think that what we do in the next three or four years will determine what 10 years from now I'll be capable of raising – or what my consumptive-use coefficient will be,"

## A View from Agricultural Producers

Paulman said. “I think that we’ll have the opportunity to make that better, and we’ll all get better together.”

Pasman is preparing his farm for Argentina’s 100-year rain cycle. He trusts the companies to develop seeds to better withstand drought, but he also is improving the farm through better no-till and irrigation practices.

Madison added that Oregon producers struggle with “rate and duty” water rights, which don’t incentivize farmers to use water efficiently because of restrictions about where and how much water can be applied. The ability to spread allocated water over more acres would encourage greater efficiency. In addition, permission to pump Columbia River water is triggered by calendar dates, which doesn’t allow for annual environmental fluctuations. A more adaptive policy would be beneficial, he said.

**Audience question:** *Can Madison provide more information about the farm’s groundwater recharge projects?*

The recharge project applies surface water from a creek running through the property to a land area that allows it to filter into the groundwater system, where it is collected and injected into a confined basalt aquifer, about 500 feet deep. Farmers are allowed to take out 98 percent of the water when needed. As expected, slight rises in the water table have resulted, and the aquifer should slowly be recharging.

**Audience question:** *As large-scale U.S. producers, what do you think is transferable to small-land*

*farmers in Africa? Can the Water for Food Institute, which is addressing large-scale U.S. needs, also handle thinking about African farmers?*

Olsen has traveled to southeast Asia, Russia and Turkey, which have some similarities to western Nebraska. He believes some of the technology he uses can be transferred there but also would like to try some of those countries’ most sophisticated equipment in Nebraska. He relayed stories about a Vietnamese farmer and agricultural students in Japan to illustrate that although farming is different elsewhere, similarities – and opportunities to learn from each other – also exist. “It makes no difference what size of a farm it is,” Olsen said. “A small farm can be just as successful as a large farm. ... I do believe that we can share with one another, and we can share what we’re doing.”

Pasman said transferring basic agronomic practices, such as row distance and density, would be helpful. In addition, he believes no-till farming would be extremely helpful for Africa, aided by Roundup Ready® seeds. The same technology for a large farm can be beneficial to very small farms. The difficulty is that yields for no-till crops are low for the first year or two, and new, cheaper irrigation systems for small farms also are needed.

**Audience question:** *What does Pasman believe is the role of government policy, especially trade policy, for the agricultural sector’s success?*

Free trade results in development around the world, Pasman said. Production increased after Argentina allowed free trade for important

technology. Argentina still has a 35 percent duty-export tax for soybeans, a policy Pasma said he opposes. In addition, universities and governments must invest in development and extension services that help farmers.

**Audience question:** *What are Paulman's incentives to grow a variety of crops? To what degree is sustainability involved in choices?*

Many components play a role, Paulman said, but he manages for a five-year water supply, both rainfed and supplemental. High water-use crops, such as alfalfa and sugar beets, hit his upper water capacity quickly. He also strip tills and manages for off-season water loss using a stripper header. "I'm keeping that water on my ground and I'm actually inhibiting return flows to the river, but I'm penalized for that because I pump that during the season," Paulman said. Ultimately, he's trying to achieve sustainability in a five-year rotation while balancing input costs and gross revenue.

Olsen said he was concerned that too few young people are studying agronomy. Farming has changed dramatically over the past 40 years thanks to university researchers, many of whom are retiring. "I'm really concerned where we're going to get the next generation of scientists that's going to be there to advise us farmers on how to raise our crops, how to use our water," Olsen said.

Technology is getting sophisticated, and it's difficult to find people capable of running the equipment, doing the research and talking to farmers about producing the world's food.

**Moderator Gustafson:** *What do the panelists need from U.S. and Argentine universities to stay competitive and sustainable?*

Pasma said in Argentina, getting research to the farmers is a problem. Transferring technology and exchanging information between countries and between universities is necessary to advance. It's also important to help farmers in countries that don't have the technology by developing low-level technology.

Paulman said he agreed, adding that producers' abilities and ingenuity are also underused. Much time is spent thinking at high levels, while the farmer is left waiting to see what happens. It's hard to understand the multiple layers, such as trade, affecting farming on a global scale.

Madison expressed concern that university research is languishing in the laboratory without a mechanism for applying it in the real world. "How can we incentivize the transfer of that information into an application, into something that's going to make changes at the production level or at the research level or in the private sector or in the public sector?"

Olsen said he was concerned that too many government regulations will hurt agriculture's future. For example, could the government take away Monsanto's new Roundup Ready® seeds or other new technologies? Or could regulations, such as the Clean Water Act or Clean Air Act, change farmers' practices? As president of the Nebraska Farm Bureau, Olsen works with farmers to oppose harmful regulations. "The whole issue of regulations, I think, is one we have to take very seriously as we look at the future of agriculture," Olsen concluded.

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# CLIMATE CHALLENGES TO WATER FOR AGRICULTURE

# Climate Challenges to Water for Agriculture

## Panel

### Nguyen Hieu Trung

Dean of the College of Environment and Natural Resources,  
Can Tho University, Vietnam

### John (Jack) F. Shroder

Professor of Geography and Geology, University of Nebraska at Omaha

### Donald Wilhite, Moderator

Director and Professor, School of Natural Resources,  
University of Nebraska–Lincoln

*The session addressed the challenges of climate change in Vietnam's Mekong Delta and the Western Himalaya and Hindu Kush regions. One speaker discussed how farmers cope with climate variability, what scientists can learn from them and how to develop large-scale strategies for the future. Another speaker discussed Afghanistan's challenging environmental problems and the consequences of glacial melting.*

## Impacts of Weather Variability on Rice and Aquaculture Production in the Mekong Delta

### Nguyen Hieu Trung, Can Tho University, Vietnam

Although farmers in Vietnam's Mekong Delta adapt to current weather variabilities, they may be unequipped to deal with future changes in global climate, Nguyen Hieu Trung said. He presented results from a study investigating the impacts of weather variability on rice and aquaculture production.

To cope with seasonal flooding as well as limited water and salinity intrusion during the dry season, Vietnam developed a rice irrigation system using canals and sluice gates. Cropping calendars and diversification also were introduced.



Nguyen Hieu Trung

Today, in dry fields, farmers cultivate rice and fish together. Farming is typically done on a small scale, with most producers managing less than a hectare or two.

To date, the system yields well, but climate variability is predicted to increase temperatures, reduce rainfall and raise sea levels, threatening productivity in the delta.

Trung and his colleagues investigated the impacts of short-term weather variability on rice and aquaculture production to suggest adaptive strategies for the future. Using weather statistical series data from 1990 to 2008, participatory-community appraisals and individual household-structured interviews, the researchers analyzed the effects of weather variability on agriculture and aquaculture production to determine how farmers adapt to weather and climate variability.

The results indicate that farmers use a cropping calendar based on weather variables. For example, farmers recognize that every two to four years, low January temperatures and abnormally high February rainfall cause a 0.6-ton loss per rice paddy, which is consistent with statistical data. When the temperature increases 1 degree in aquaculture settings, shrimp yields decrease 0.7 ton per hectare.

The study illustrates that scientists can learn much from farmers about how weather variation affects their experiences and strategies. “This is very important for our assessment of the vulnerability of climate change in the future,” Trung said.

For rice production, farmers cope by integrating nutrient management to help rice better tolerate



Harvested rice bundles

weather anomalies and by using appropriate rice cultivars and cropping calendars. Farmers also irrigate using groundwater, which is illegal, and create field ditches to drain the surplus water and to prevent soil acidification, a problem in the Mekong Delta. To reduce temperature’s impact on aquaculture, farmers deepen ponds, adjust feed and exchange pond water for intensive *Pangasius catfish* culture. In shrimp ponds, farmers grow aquatic plants to stabilize the temperature and reduce water pollution. The household’s economic livelihood strongly influences coping measures; poor households are the most vulnerable, with low resilience to change.

Adaptation strategy is a time-dependent and location-specific learning process, Trung said. “We should have a systems approach, which includes an integral combination of agriculture production system and food security and livelihoods, and this approach should be from top down and bottom up.”

# Climate Challenges to Water for Agriculture

Although rice does not always provide the highest income, it is extremely important for Vietnam's food security and will remain the delta's primary crop. Trung and his colleagues recommend providing farmers a choice of technological packages, such as adaptive cultivars, farming practices and integrated farming systems. In addition, farmers need crop yield forecasting and simulation models to identify measures to minimize weather variables.

On a larger scale, adaptive strategies must be implemented within the context of improving rural people's livelihoods and of ensuring food security at the household, regional, national and global levels. Strategies must include appropriate policies to enhance farmers' adaptability, and

they must integrate a top-down approach with the bottom-up vulnerability perspective approach. The integration of the two approaches has been limited.

The impacts of temperature and rainfall variability differ among crops and their development stages, and within regions and seasons. Local people have ways to cope with weather variability, but they have not fully identified adaptation strategies for rice and aquaculture in the event of climate change, Trung concluded. Vietnam must develop additional strategies for future hydrological changes from global warming and upstream dam construction that will bring less water to the Mekong Delta.

## Change in the Western Himalaya and Hindu Kush

**John (Jack) F. Shroder**, University of Nebraska at Omaha

John (Jack) F. Shroder helped found the University of Nebraska at Omaha's (UNO) Center for Afghan Studies in 1972. Since then, he has been involved in numerous research projects on Afghanistan's environment and studies of glaciers in the Himalayas.

As director of the Atlas of Afghanistan Project in the early 1970s, Shroder became involved in Afghanistan's environmental problems, including deforestation and "deshrubification," overgrazing, salt buildup, desertification, soil erosion, increasing aridity and decreasing water supply in an extremely dry environment.



John (Jack) F. Shroder

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Contributing to Afghanistan's problems is Bad-i-sad-o-bist-roz, or "wind of 120 days," which blows 100-knot winds from July through September, causing damaging soil erosion. Lakes, rivers and agricultural fields have dried up, leaving sand dunes vulnerable to the powerful winds. In addition, degradation of grazing lands in the mountains throughout Pakistan and Afghanistan causes mud flows during the monsoons, bringing rocks and boulders crashing down. Poor people are left to deal with this dry, hostile land.

Among many other projects, Shroder has been involved in flood modeling for NATO and mapping the Afghan-Soviet border before the Soviets invaded, work that recently drew the interest of Afghan President Hamid Karzai.

Glaciers are a major focus in the area, the importance of which has increased with predictions of glacial melting caused by climate change. Glaciers are important storehouses of water and are by far the biggest potential sources of water for humans in the future. About 10 years ago, the Global Land Ice Measurements from Space (GLIMS) Regional Center for Southwest Asia was created at UNO to monitor glaciers in Afghanistan and Pakistan. GLIMS eventually will be passed to the Afghans and Pakistanis.

GLIMS has found that many glaciers are in trouble, Shroder said. The Koh-i-Foladi glacier, Mir Samir glacier and others in the Wakhan Pamir have shrunk dramatically and many smaller ones have disappeared in the past 50 years. "This is not good news for Afghanistan because it means a gross diminishment of water

coming downstream, particularly for the late summer and the early fall crops," Shroder said.

In contrast, he discovered that some glaciers are actually growing in areas of the Himalayas. Two reasons explain the surprising phenomenon: 1) an increase in mass at high altitude, from such causes as numerous snow avalanches following an earthquake, and 2) melting at lower altitudes, which accelerates forward motion. More surging glaciers are occurring in the Himalayas than anywhere else in the world, an event that Shroder termed the Karakoram Anomaly.

In 2008, the Cryosphere and Hazards Workshop in Kathmandu, Nepal, brought together Indian, Pakistani, Chinese and American geoscientists to discuss the region's delicate water issues. Following the workshop, in which Shroder announced the Karakoram Anomaly occurring in Pakistan's glaciers, geoscientists determined that India's Karakoram glaciers, too, are growing because of greater winter moisture.

Threats remain. As permafrost warms, it melts the Himalayan slopes, causing large rockslides. One occurred in Hunza in January 2010, forming a massive lake that threatens to blow out and destroy bridges on the Indus River. The Tarbela, the world's largest earth-filled dam, also sits downstream and will either contain the water or be destroyed. "Change is coming in the Himalayas and Hindu Kush, just like it always has," Shroder concluded. "Drought in some places, too much water in others, and the change probably won't be quite what we expect anyway."



A close-up photograph of a green leaf, likely a corn leaf, with numerous small water droplets on its surface. The leaf is the central focus, with a dark, blurred background. The lighting highlights the texture of the leaf and the glistening of the water droplets.

## KEY ISSUES FOR THE FUTURE

## Key Issues for the Future

### Panel

#### **Ken Cassman**

Heuermann Professor of Agronomy and Director, Nebraska Center for Energy Sciences Research, University of Nebraska–Lincoln

#### **Eugene Glock**

Producer, Cedar Bell Farms, Nebraska

#### **David Molden**

Deputy Director General for Research, International Water Management Institute

#### **Peter Rogers**

Gordon McKay Professor of Environmental Engineering, Harvard University

#### **Prem S. Paul**, Moderator

Vice Chancellor for Research and Economic Development, University of Nebraska–Lincoln

*This panel discussion addressed what participants learned at the conference, goals for the Water for Food Institute during the next three years and perspectives on the most pressing questions facing researchers, producers, policymakers and organizations interested in water issues.*



From left: Peter Rogers, David Molden, Eugene Glock, Ken Cassman and Prem S. Paul

## Important to Nebraska and Important Globally

### Ken Cassman, University of Nebraska–Lincoln

Ken Cassman offered three thoughts to guide the Water for Food Institute: 1) engaging young people is important; 2) irrigated agriculture has a reputation, even in Nebraska, as being bad for the environment and the economy, yet irrigated agriculture will play a significant role in a Green Revolution in Sub-Saharan Africa, although that role has yet to be defined; and 3) research and education conducted at the institute must benefit Nebraska, contribute to the university's land-grant mission and be fundamentally important internationally. "What that means to me is the institute, early on, has to be very successful at picking foci and priorities for their efforts that can be articulated very clearly as important to Nebraskans and important globally," Cassman said.

Because resources won't be enough for separate agendas, issues the institute focuses on must benefit Nebraska's interests and international interests while using the same teaching and research expertise.



Cattle in Nebraska's Sandhills



Eugene Glock (left) and Ken Cassman

Cassman said one example would be to answer the questions: Can high-yield, irrigated agriculture be sustainable in terms of food supply, economics and social acceptance? How can policymakers be convinced that irrigation is sustainable? How can purchasers or donors be convinced that irrigated agriculture can be part of development plans?

A second example might be to conduct life cycle assessments of agricultural systems' water footprints. For example, studies demonstrate that lettuce grown efficiently and trucked elsewhere contributes fewer greenhouse gases than locally produced lettuce. Similarly, feedlot cattle have lower greenhouse gas emissions per unit of meat produced than do grass-fed beef. Understanding agriculture's water footprint will require interdisciplinary integration, Cassman said.

## Key Issues for the Future

### An Unbiased Source of Information

#### Eugene Glock, Cedar Bell Farms

Eugene Glock emphasized the importance of compiling and disseminating information. “If you’re trying to push it on people, it’s not going to happen. But if you can show people some way that it’s going to benefit them personally, economically, socially, some way that it will be helpful, they’ll adopt that pretty quickly.” He gave the example of high-pressure pivot irrigation, which uses less water. Although lower pressure pivots are less expensive, when diesel fuel reached \$4 per gallon and it cost up to \$30,000 to add an inch of water to a field, people reconsidered high-pressure irrigation. “That’s what we have to strive for, and that’s what this institute has to have a hand in doing – getting people excited about doing something that is right, not trying to force them,” Glock said.

He also urged the institute to avoid becoming a lobbying agency, but rather to be available to



Eugene Glock

help policymakers make good decisions. Glock, who was the state agriculture representative on former U.S. Sen. Bob Kerrey’s staff, said he believes policymakers need an unbiased center to help determine worthwhile projects to fund.

### Filling the People and Research Gaps

#### David Molden, International Water Management Institute

David Molden believes the institute could fill a “people gap.” Too few people are trained to address water issues, he said. Even the International Water Management Institute (IWMI) has difficulty hiring specialists, including economists.

The shortage of professionals leads to a research gap. IWMI collaborates with universities to fill that gap, taking cutting-edge science and adapting it to local settings. “I think the two



David Molden

major gaps, then, that this institute can fill are really good research ... and a lot more human capacity,” he said.

Water management must change, Molden urged, and it must include an arsenal of solutions, from crop varieties and no-till conservation, to drainage and large-scale irrigation. To appeal to young people, water management must be pitched as a broad, exciting field that also

encompasses politics, social science and ecology. Finally, he said, the institute must reach outside the U.S., really listen to people’s concerns and try to solve those problems.

“There are many players in the game,” Molden said. “The Africans, for example, ... want to take the future in their hands. ... I can only see great collaboration within and would just ask you to step out now into the rest of the world.”

## Putting the Knowledge into Action

### Peter Rogers, Harvard University

Peter Rogers summarized discussions he heard at the conference, from Pedro Sanchez’s good news regarding Africa’s ability to increase production from 1 ton to 3 tons, which would greatly impact health and economic status, to irrigation’s role in the Green Revolution, which Ken Cassman addressed. “I don’t think we have that for the second Green Revolution,” Rogers said. “We don’t have the land area to expand on. The issue is going to be: How can we do that within the next 20, 30 years?” However, Rogers said he heard little about the negative impacts of climate change, although it was suggested that climate change may result in a 20 to 40 percent reduction in crop production.

He also emphasized an important lesson from Australia regarding the need for institutional reform prior to introducing economic reforms. “We think we can get the market to work its magic and wonders without changing the institutions,” Rogers said. “And I think the

important thing there is that the institutions for water management and regulation are absolutely fundamental, if we’re ever to take advantage of the powerful economic tools we have.”



Peter Rogers

He conveyed cautious optimism regarding increasing water productivity, irrigation efficiency and new varieties and technologies. Climate change is an unresolved issue, however, and Rogers said he believes climate variability will cause many problems requiring attention.

## Key Issues for the Future

“But the biggest impression is that political and institutional issues predominate,” Rogers said. “Basically, we have the know-how. We need to establish the can-do.” That will require taking information to the political arena to rearrange institutions and take advantage of what is already possible.

Rogers also emphasized communication. He recommended establishing media contacts through an annual program to bring journalists and media specialists to Nebraska to learn about agriculture. In addition, Rogers said, because intellectual elites on the coasts tend to know little about agriculture, faculty seminars or collaborations would encourage greater understanding, particularly for economists.



Peter Rogers (left) and Prem S. Paul

## Questions and Answers

**Moderator Prem S. Paul:** *If the Water for Food Institute accomplished one impressive thing by next year, what would it be? Within three years?*

Eugene Glock said a framework of the institute’s management structure should be established within the next year. He also pointed out that both smallholder farmers in Africa and large-scale farmers in the U.S. want to produce more with available resources. “I would hope that the institute is moving in the direction to pull things together,” Glock said. Within three years, Glock said he hopes the institute has made progress in compiling research happening worldwide and analyzing ways to best use available resources.

David Molden said within one year he would like a better understanding of critical gaps the

institute wants to fill and to see some quick results. In three years, Molden said he envisions a conference with twice as many attendees, half of whom live outside the U.S.

Peter Rogers recommended scouring the globe to find farmers to attend next year’s conference. “I think we could learn a lot from other farmers from other parts of the world,” he said. International attendees also could take the conference’s message back to their communities. In three years, Rogers said the institute and collaborating institutions should be pushing the U.S. research agenda, through the National Science Foundation, to spend more money on water issues and support young researchers. He also hopes more interested young people will attend the conference.

Ken Cassman said he was impressed that so many young faculty from a wide range of disciplines attended the conference. He said the University of Nebraska–Lincoln should further engage young faculty from diverse fields, such as computer science, education, environmental sciences and journalism, ensuring that they, too, have a stake by selecting priorities that generate excitement. Cassman said his three-year goal for the institute is to build a reputation as an expert in key areas important to Nebraska and the developing world.

**Moderator Paul:** *Does a need exist for a repository of easily accessible information? Is that something the institute should undertake?*

Molden said he believes it's more important to add to the information base than to become an information clearinghouse.

Rogers said he agreed, adding that clearinghouses require significant money, staff and dedication. Over time, remaining consistent becomes difficult and data quality degrades when resources and efforts flag.

**Moderator Paul:** *What is the most critical research area to increase water productivity in crops?*

Molden said studying the consumptive use and evapotranspiration component at a range of scales is important because it drives river depletion and groundwater decline.

Glock said he is optimistic that science will meet future needs but is concerned about getting advances to farmers. "We already have a whole lot more science that tells how we can save

water and produce more with limited resources than we're using," he said. "Getting it out to the people that need it is what we have to do, and that is a very difficult situation to tackle." The current adoption rate is too slow to address future problems, but younger people may adapt more quickly than his generation, Glock said.

**Moderator Paul:** *How do we get products and services from sustainable water use activities to be more valuable than those from unsustainable activities?*

Raising the price of resources forces more efficient use, but is efficiency more sustainable? Cassman asked. A solid analytical framework with measurable, agreed-upon metrics of what constitutes sustainability would answer that question. "That's certainly an area that I see as a crying need, one that a center like the Water for Food Institute could take a major leadership role in," Cassman said.

Rogers cautioned against solving problems by raising prices. He cited an example in Orange County, Calif., where a utility switched to recycling wastewater, not because of pricing, but because the U.S. Environmental Protection Agency (EPA) enforced water quality regulations. Forced to use tertiary treatment, the utility decided to recycle water completely, eliminating huge demand to ship water from northern California and improving water issues there as well. Similarly, the EPA's requirement to monitor 114 chemicals will require wastewater treatment plants to convert to reverse osmosis, which also may lead to significant efforts to recycle wastewater. "We have a strong regulatory system," Rogers said. "You may not like the

## Key Issues for the Future

EPA, but the EPA is regulating us, and we have a general consensus that's worth doing.”

**Moderator Paul:** *What role should private companies have?*

Because public resources for research are declining, private industry must be involved, Glock said. However, that creates new challenges because while industries pay universities for research, they keep the resulting product. “How can we get private industry involved in helping to pay and at the same time make it available to help those people who can't afford to pay for it?” Glock asked.

Water is a huge issue for the private sector, Cassman added. It will be important to identify intersecting issues of importance to the private sector, the developing world and Nebraska.

Rogers said as long as the private sector performs well, concern about its involvement is irrelevant. The issue is ensuring good performance. Some disasters involving water privatization were primarily caused by government failures and a lack of institutions and frameworks regulating private companies. “There is a role for profit-making in even things like water,” he said. “Particularly if they [the private sector] can provide adequate or better services than the public sector.”

Molden cautioned against considering the private sector as only big, international companies. It also includes small-scale private enterprises in other countries. Engaging small businesses in inputs and outputs, such as manufacturing and repairing pumps, would stimulate economies.

Could big U.S. companies downscale technologies to help out? he asked.

Paul said private-public partnerships play important roles at UNL because without them, some new technologies would not reach the marketplace. Companies also can provide capacity building, such as funding for the next Water for Food conference and travel grants for international participants. However, UNL must remain unbiased to maintain credibility, he said.

**Moderator Paul:** *Is there enough renewable groundwater and surface water in Sub-Saharan Africa to sustain irrigated agriculture?*

Yes, Molden said. “I always question what kind of irrigation? Big scale, small scale – you need all of it, all together.”

**Moderator Paul:** *Can American farmers produce enough corn and soybeans for feed, food and fuel while using less water on less land and fewer inputs? Also, is it wrong to use crops for biofuels?*

Glock said with the scientific community's help and with proper adoption, these requirements can be met, adding that biofuels are effective and worth producing.

Cassman said that perhaps the biofuel program's most important contribution has been to raise the value of agriculture.

**Moderator Paul:** *What role should organic agriculture play in this program, particularly as consumers become more environmentally conscious?*

A range of solutions must be considered, including eco-agriculture approaches, Molden said. If smallholder producers are allowed to make money by marketing in the city, why not allow organic agriculture? he asked.

Glock said he does not object to organic agriculture. Many farmers use no-till and as few inputs as possible, “but if you want to feed the world, sometimes you have to do some things that other people may not approve of.”



Farmers in Angola with their potato crop

**Moderator Paul:** *The world does not lack water, but rather water of appropriate quality. What is the cost of bringing water to the appropriate quality and location?*

Rogers responded that in the next 100 years, desalination will be inexpensive enough to provide the world’s water needs; similarly, the cost of electricity will come down after shifting away from fossil fuels. The issue is affordability in the next 20 to 30 years. Desalination is already cost effective for industrial and municipal supplies, but only in limited areas for agriculture, such as North Africa, which has strong interest in creating agricultural employment.

Molden said desalination costs about 50 cents per cubic meter, but will have to drop to about 3 cents per cubic meter to be viable for agricultural uses.

**Moderator Paul:** *If many Nebraskans don’t understand irrigated agriculture’s benefits, what role does land-grant extension play?*

Glock said the university’s main role is to provide information. Producers are the people responsible for communicating the importance of agriculture, he said. The institute should avoid becoming a lobbying organization, but it can provide information to promote the research and to analyze policy.

Cassman disagreed. Scientists have great influence with policymakers, he said. “Deeply flawed” biofuels research from leading universities had great sway with policymakers, he said, and growers don’t have the data to convince policymakers. “We don’t have the quantitative framework with regard to all the dimensions of what those benefits are. That’s why this institute could play a key role in helping those that care about water for agriculture make their case.”

# Appendix





POSTER COMPETITION,  
CONFERENCE PARTICIPANTS  
AND PHOTOS

## Poster Competition

The 2010 Water for Food Conference included a juried poster competition. Fifty-seven posters were entered in three key categories that reflected the major conference themes and an “Other” category for related topics. University of

Nebraska–Lincoln (UNL) faculty members and graduate students and Water for Food advisory committee members served as jurors. The first place poster presenter in each category received a \$250 prize.

## Technologies and Advances in Water Management

### Jurors:

**Derrel Martin, Richard Sincovec, Deepti Joshi and Ron Yoder, UNL**

### First place:

**Agnelo Silva, UNL**

Wireless underground sensor networks for autonomous water management

### Outstanding merit:

**Joon Kim, Yonsei University, Seoul, Korea**

Partitioning of catchment water budget and its implication for ecosystem production

**Jennifer Rees, Southeast Research and Extension Center, UNL, Clay Center, Neb.**

The Nebraska Agricultural Water Management Demonstration Network: Integrating research and extension

### Other presenters:

**James Cannia, Wyoming Geologic Survey, Conservation and Survey Division, North Platte Natural Resources District, Department of Natural Resources and the U.S. Geological Survey, Mitchell, Neb.**

Heliborne electromagnetic surveys to be used for aquifer identification and quantification

**Greg Cutrell, UNL**

Analysis of the energy and water balance of a temperate wetland and the response to changes in climate and vegetation

**Dean Eisenhauer, UNL**

Soil hydrology of no-till, center-pivot-irrigated cropland

**Gary Hergert, Panhandle Research and Extension Center, UNL, Scottsbluff, Neb.**

Managing with less water in western Nebraska: The Pumpkin Creek Watershed Demonstration and supporting crop response data on limited irrigation

**Christina Hoffman, UNL**

Geospatial mapping and analysis of water availability, demand and use within the Mara River Basin

**Baburao Kamble, UNL**

Developing an integrated hydrological information system for Nebraska

**Robert N. Klein, West Central Research and Extension Center, UNL, North Platte, Neb.**

Skip-row corn in southwest Nebraska to improve drought tolerance of rainfed corn

**Jake LaRue, Valmont Irrigation Inc., Omaha, Neb.**

Mechanized irrigation of rice: Improving water conservation and quality

**Xu Li, UNL**

Developing water treatment systems for small communities

**Chengpeng Lu, UNL**

Parameter estimation for a Karst aquifer with unknown thickness using genetic algorithm and improved search bounds

**Karen O'Connor, Olsson Associates, Lincoln, Neb.**

Using GIS to manage glacial aquifers of eastern Nebraska

**Blake Onken, Lindsay Corp., Omaha, Neb.**

Utilizing mechanized sprinkler systems to reduce water use in rice production

**Otto Szolosi, Irrig8Right Pty Ltd., Narre Warren, Victoria, Australia**

Water recycling as an alternative water source

**Tsegaye Tadesse, National Drought Mitigation Center, UNL**

Scenario-based vegetation outlook (S-VegOut): Predicting general vegetation condition using different scenarios over the central U.S.

**Jessica Torrion, UNL**

SoyWater: A Web-based irrigation decision aid for soybean producers in Nebraska

**Tom Trout, U.S. Department of Agriculture-Agricultural Research Service Water Management Research Unit, Fort Collins, Colo.**

Water productivity for high plains crops

**Charles Wortmann, UNL**

Improving sorghum production in water deficit production environments of eastern Africa

**Jinsheng You, UNL**

Interactions among climate forcing, soil water and groundwater through monitoring: Concept project

## Human Dimensions of Water for Food Production

**Jurors:**

**Karina Schoengold, Raymond Supalla and Chris Thompson, UNL**

**First place:**

**Federico Trindade, UNL**

Is there a slowdown in agricultural productivity growth in South America?

**Other presenters:**

**Craig Allen, U.S. Geological Survey Nebraska Cooperative Fish and Wildlife Research Unit and UNL**

Resilience and adaptive governance in stressed watersheds

**Sanjay Chakane, University of Pune, Maharashtra, India**

Continuous contour trenching tool for watershed management

**Ayako Ebata, UNL**

Agricultural productivity growth and irrigation in Central America and the Caribbean

**Tonya Haigh, National Drought Mitigation Center, UNL**

Farmer perceptions of conservation and sustainable agriculture practices and drought risk reduction in Nebraska

## Poster Competition

**Joseph Hamm, UNL**

Exploring separable components of institutional confidence

**Francine Rochford, La Trobe University, Australia**

“I don't know where our water is going”

**Emile Salame, UNL**

Agricultural productivity in Lebanon and its surrounding countries

**Steven Shultz, University of Nebraska at Omaha**

Stakeholder willingness to pay for watershed restoration in Bolivia, South America

**Otto Szolosi, Irrig8right Pty Ltd, Narre Warren, Victoria, Australia**

Irrigation industry reform: Issues, impediments and recommendations

**Nicole Wall, National Drought Mitigation Center, UNL**

The National Drought Mitigation Center (NDMC): Science and expertise that serve agriculture on a national and international scale

**Wayne Woldt, UNL**

The WATER machine: Engagement of stakeholders in water education

**Donna Woudenberg, National Drought Mitigation Center, UNL**

Water for food: Gender and cultural considerations

**Gary Zoubek, Southeast Research and Extension Center, UNL, York, Neb.**

Irrigation and energy conservation field days and workshop: University of Nebraska–Lincoln Extension, Nebraska Corn Growers and Nebraska Corn Board working together

## Genetics and Physiology of Crop Water

**Jurors:**

**Mark Lagrimini** and  
**Roberto de la Rosa Santamaria, UNL**

**First place:**

**Ismail Dweikat, UNL**  
Seedlings cold tolerant sorghum serve as drought avoidance

**Outstanding merit:**

**Saadia Bihmidine, UNL**  
Improving crop drought tolerance through biotechnology

**Walter Suza, Arkansas State University, Jonesboro, Ark.**

Exploring the role of sterols in plant response to drought stress

**Other presenters:**

**Patricio Grassini, UNL**  
Farming near yield potential and resource use efficiency ceilings: A case study of irrigated maize in Nebraska

**John Lindquist, UNL**

Water use efficiency of maize and velvetleaf (*Abutilon theophrasti*)

**Tejinder Mall, UNL**

Improving end-use functionality of grain sorghum

**Joseph Msanne, UNL**

Characterization of the abiotic stress-responsive *Arabidopsis thaliana* RD29A and RD29B genes and evaluation of transgenes

**Justin Van Wart, UNL**

Establishing yield potential in drastically different precipitation regimes: How many years of weather data are required to estimate crop yield potential?

## Other

### Jurors:

**Peter Rogers, Harvard University;**

**Judith C.N. Lungu, University of Zambia;**

**James Goeke, UNL and U.S. Geological Survey;**

**Arthur Zygielbaum, UNL**

### First place:

**Yi Peng, UNL**

Remote sensing of crop primary productivity: From close range to satellite observations

### Outstanding merit:

**John T. Li, UNL**

Removing natural estrogens from drinking water using a biologically active carbon (BAC) reactor

**Jason Vitek, UNL**

Chlorella virus distribution in Nebraska rivers

**Jerry Kenny, Headwaters Corporation, Kearney, Neb.**

Platte River Recovery Implementation Program

### Other presenters:

**Shannon Bartelt-Hunt, UNL**

Occurrence of steroid hormones and antibiotics in groundwater impacted by livestock waste control facilities

**John Gates, UNL**

Sustaining mega-aquifers for food production in complex agricultural landscapes: Groundwater replenishment in the American High Plains and North China Plain

**Rachael Herpel, UNL**

University of Nebraska–Lincoln Water Center

**Tim Hiller, UNL**

Endangered species recovery and water management on the Missouri River: Implementing an adaptive management approach

**Matthew Kerrigan, UNL**

Increasing demand for drinking water research

**Aziza Kibonge, UNL**

Agricultural productivity and water availability

**Jamie McFadden, UNL**

Predicting management implications on the Lower Platte River, Nebraska, for interior least tern and piping plover: A practical application of a quantitative model

**Kristine Nemec, UNL**

Grassland diversity and ecosystem services within an agroecosystem

**Camilla Rice, UNL**

Demonstration art in a depleting water supply

**Drew Tyre, UNL**

The pallid sturgeon habitat assessment and monitoring program: 2007-2009

# Conference Participants

## Abbreviation Key:

**CSIRO:** Australian Commonwealth Scientific and Industrial Research Organisation

**UNL:** University of Nebraska–Lincoln

**USDA-ARS:** U.S. Department of Agriculture-Agricultural Research Service

**USGS:** U.S. Geological Survey

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# Photos



Future home of the Water for Food Institute



David Molden and Don Wilhite



Michael K. Doane and Katherine Lombardo



Judith C.N. Lungu, Elijah Phiri and Richard Berkland



Randolph Ferlic



Alan Moeller, Mark Gustafson, Rolando Flores and Elbert Dickey



John Gates



Water for Food Senior Advisory Council



Kenneth Morrison, James B. Milliken and James McClurg

# Photos



Krishna C. Prasad



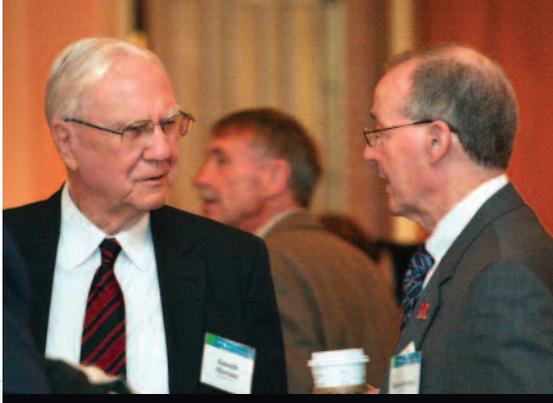
Peter Rogers, Robert Meaney and Mike Young



Martin Pasman, Roric R. Paulman and Keith Olsen



Susan Fritz



Kenneth Morrison and Harvey Perlman



Jeff Raikes, Mogens Bay and Tim Daugherty



Kenneth Morrison, Sen. Tom Carlson and Tom Osborne



Joel Sartore and Prem S. Paul



Blake Onken and Michael Hayes

# Photos



Jason Clay and Michael K. Doane



Marcos Folegatti and Roberto Tuberosa



Arthur Zygielbaum, James Goeke and Kristine Nemeč



Pedro Sanchez and Randy Pryor



Conference recognition banquet



Richard Sincovec and Mohamed Dahab



Thomas Farrell, Nguyen Hieu Trung and Carolyn Fuller



John Anderson and John Briscoe



Larry Tieszen, Robert Swanson and W. Don Nelson



Munir Hanjra and U.N. Panjjar

