Paths to Solutions

Proceedings of the 2011 Water for Food Conference

Lincoln, Nebraska – May 1-4

University of Nebraska

Water for Food

Robert B. Daugherty Institute

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Foreword

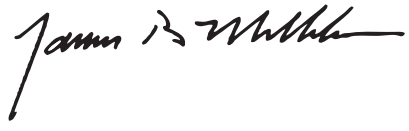
By now, the estimates are becoming alarmingly familiar: We may need to double food production by 2050 to feed an expected population of more than 9 billion people, and we must do it using less water than we use today.

Since we held the Future of Water for Food Conference in 2009, bringing together experts from around the world to discuss the need to grow more food with limited water supplies, the linked issues of water security and food security have gained increasing attention as one of the greatest challenges facing the global community.

The Robert B. Daugherty Water for Food Institute was established in 2010 to focus research, education and policy analysis on the complex problems of ensuring sufficient food and water supplies for current and future generations. Mr. Daugherty, who devoted his career to improving agriculture through innovative irrigation systems, knew that research and innovation were keys to agricultural productivity and feeding our growing world population. And this is one of the driving forces of the Daugherty Water for Food Institute: moving innovative research, technologies and ideas out of the laboratory and into the field through creative partnerships with private and public sector organizations throughout the world.

This was the focus of the 2011 Water for Food Conference: Paths to Solutions, hosted by the University of Nebraska with the support of the Robert B. Daugherty Charitable Foundation, the Bill & Melinda Gates Foundation and Monsanto Co. The conference gave us an opportunity to learn from more than 430 people from 24 countries who shared their ideas for potential solutions. This report documents the ideas and discussions that emerged from the conference.

We hope this report will lead you to consider ways to contribute to potential solutions to this critically important global challenge.



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Executive Summary and Introduction

Executive Summary

Do we have the technologies to solve the global food and water challenge?

What is the greatest barrier to food security in developing countries?

John Briscoe of Harvard University posed these and other questions to the audience during a panel discussion with industry leaders at the third annual global Water for Food Conference. Of those who responded, 75 percent think the technology to solve the food and water challenge is already available or will be in the next decade, and 88 percent believe the greatest barrier to food security is lack of institutional capacity.

Hosted by the Robert B. Daugherty Water for Food Institute at the University of Nebraska (NU) and the Bill & Melinda Gates Foundation, the 2011 conference – Paths to Solutions – brought together more than 450 experts from universities, the private sector, governments and nongovernmental organizations around the world to discuss potential solutions for managing and using our water resources to feed an increasingly hungry and thirsty world.

While improving technology remains critical, the need to address institutional capacity and engage decision-makers played a prominent role in this year's conference. "The perception is we have quite a bit on the technology side … but how can we walk on two legs?" Briscoe asked. "How can we get the institutional framework and the technologies working together more effectively?"

Plenary Presentations

The Bill & Melinda Gates Foundation considers securing water for food one of the greatest challenges of this century, said CEO Jeff Raikes. He led the keynote discussion with Kebede Ayele, Ethiopian country director of International Development Enterprises (IDE), and Soumen Biswas, executive director of Professional Assistance for Development Action (PRADAN) in India. Each discussed his organization's efforts to lift poor, rural farmers out of poverty.

Ayele said irrigation and market access are key components to raising incomes. IDE develops simple, affordable household irrigation systems and helps connect farmers to profitable markets. He stressed the importance of viewing farmers as customers, not beneficiaries. "If they get the opportunity, the right opportunity, they can lift themselves out of poverty very quickly."

Biswas added that because many farmers believe they lack the skills they need to adopt technology and access markets, altering farmers' self-view through social mobilization also is critical. PRADAN organizes support groups through which participants educate themselves, slowly build confidence and take on increasingly complex tasks.

Indian woman carrying fodder

Raikes said, "We think technology is the magic answer but, in fact, it requires social mobilization, a change in mindset. It requires education to understand the financial benefits of the investments."

Mature ear of corn

Anil Jain, managing director of Jain Irrigation Systems Ltd. of India, agreed that providing micro-irrigation systems to smallholder farmers is key to increasing productivity and water use efficiency. Jain Irrigation helps small farmers by providing drip irrigation systems to Indian farmers. "But is that enough," Jain asked, "just delivering water in the right manner to the plant? We don't think so. If we really want a transformational impact, I think you need to look at the entire agriculture (industry) in a holistic manner." To that end, the company incorporates an integrated model that supports smallholders through irrigation, agronomic management training, on-farm water storage, research and other strategies. These changes allow farmers to produce two or three crops after the rainy season, which makes the difference between poverty and sustenance, Jain said.

The three primary challenges to securing enough water for agriculture are population growth, limited water availability and climate change, said Anders Berntell, executive director of the Stockholm International Water Institute. Also troubling is the rate of global water consumption, which is twice the world's population growth rate, predominately due to increased agricultural water use, he said.

The water requirement to feed the world in 2050 will increase 80 percent. At the same time, climate change will dramatically affect water availability. Despite these challenges, advances in agriculture will lead to greater production using less water. Other opportunities include increasing trade, shifting production of water-consuming food to water-rich regions and reducing the loss of food from "field to fork," in part by addressing low food prices. "What other commodity could we afford to lose 50 percent from production to consumption?" Berntell asked. "I'm not arguing that we should dramatically increase food prices … but it's something that needs to be looked upon."

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The dramatic increase in natural disasters suggests Earth's hydrological cycle may be changing, posing a risk to humanity and challenging food production, warned András Szöllösi-Nagy, rector of the UNESCO-IHE Institute for Water Education. "We have been playing with the hydrologic cycle over the past 300 years and very notably ever since the Industrial Revolution," he said. "However, we never understood clearly: What is the impact of tampering with the cycle?" To deal with hydrological variability, Szöllösi-Nagy urged increasing buffering capacity through water storage and tapping into unused groundwater resources. But the message that a water crisis is looming has not reached the political community, he said, emphasizing the need for reliable data that reach decision-makers and for raising the profile of water nationally and internationally through education, capacity building and partnerships. "We have to generate the political will to do things right, the capacity to do it right and the resources to do it right now," Szöllösi-Nagy said.

"We have been playing with the hydrologic cycle over the past 300 years and very notably ever since the Industrial Revolution. However, we never understood clearly: What is the impact of tampering with the cycle?"

Pasquale Steduto addressed the large gap between potential and actual water productivity in many areas worldwide, particularly in developing countries. "We need to understand what are the causes of all this, otherwise we cannot intervene," said Steduto, head of the Water Unit at the Food and Agriculture Organization of the United Nations (FAO). To understand water productivity gaps, FAO is undertaking systematic studies from the local to international levels, benchmarking crop productivity using basic statistical programs and modeling, and using remote-sensing assessments and socioeconomic analyses to identify limiting cost-benefit factors. Steduto also advocated viewing the relationship between yield and water consumption as more articulated than just a few solutions, as is common. Without a comprehensive view of crop productivity that includes water and land, agronomy, technology, the market, economics and other factors, the risk of failing to raise water productivity is high, Steduto said.

Julia Bucknall, sector manager of the World Bank's Water Department, acknowledged the important role of irrigation in increasing productivity. But investing in irrigation in developing countries often fails to demonstrate clear economic rates of return, she said, in part because public sector irrigation is frequently installed for social reasons that create barriers. "In my view, my organization and governments that work in developing countries need to think very hard about irrigation strategies." Bucknall advocated going beyond investing in irrigation to address competing demands for water and to link farmers to the market, while being cognizant of each country's capacity. "I believe it is a huge mistake to put in place policies and technologies that are not compatible with the institutional capacity and political will of the country in which they're operating. I believe it will worsen the situation," she said. Global trade policies also should reflect the reality that small countries don't trust the food trade system, and Bucknall said she worries that food won't be distributed properly.

Peter Saling, head of BASF's Eco-Efficiency Analysis Unit, described his company's experience conducting sustainability evaluations, which reduce reputational risks and create value for the company and its customers. To evaluate sustainability – defined as an equal balance between economy, ecology and society – BASF calculates social implications, life cycle assessments, environmental impacts and economics to develop an overall eco-efficiency portfolio. As BASF moved into evaluating sustainability in agriculture, it developed a tool that encompasses agronomic characteristics, including water. A comprehensive water use fingerprint is developed by determining water availability and withdrawal, as well as damage to ecosystem quality, resources and health. Water is only one component of many in determining overall sustainability, Saling said. BASF uses sustainability evaluations to make strategic investment decisions, demonstrate product advantages, filter research ideas and inform legislative decisions.

Center pivot with drop sprinkler heads

Panel Discussions

A View from Industry

A panel of business leaders agreed that technology to increase agricultural production is advancing rapidly, but lagging behind are the public institutions necessary to provide infrastructure, regulatory systems and market access, particularly in developing countries. Private companies should help the public sector develop the capacity to boost global agricultural production. "There's a great deal that we can do when we get our technologies, our infrastructure – the private sector and the public sector – working together," said moderator John Briscoe of Harvard University. Assisting in establishing independent monitoring systems might be one way for private companies to help governments build capacity, he said.

Kerry Preete, Monsanto Co. senior vice president, described the company's engagement with governments and said it would like a common set of regulations, developed globally and run by government institutions. "When there is no regulatory system, the products don't get there," he said, resulting in lack of choices for the farmer.

Philanthropy also will play a bigger role in developing regulatory systems in the future, added Mogens Bay, chairman and CEO of Valmont Industries Inc. "I think we have plenty of examples of philanthropy standing in where government is not doing as good a job as it should," he said.

Carl Hausmann, managing director, Global Government and Corporate Affairs at Bunge Ltd., issued a cautionary note about the boundaries of public-private relationships. He agreed that private-sector voices should be heard, but "societies need to be governed locally, not by

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the private sector." Hausmann also raised questions regarding land and water availability, preserving biodiversity and labor issues. "I'm convinced that we will meet this demand," he said. "How sensitive we are in meeting this demand going forward, I think, is really the critical thing we all need to think about."

A View from Producers

The technology is available to meet 2050 agricultural targets, but it will require a sustained vision and effort, agreed a panel of producers from several of the world's farming regions. James Cartwright of Vegpro Kenya Ltd., Kenya's market leader in horticulture and floriculture, described his company's multiple irrigation methods that accommodate a wide variety of crops. Water management changes have resulted not only in 21 percent water savings in vegetable production and 11 percent savings in roses, but also in healthier plants. Vegpro employs more than 7,000 people, which translates to supporting about 60,000 people, and works with 3,500 small-scale farmers. Cartwright urged development projects not to ignore commercial farmers. "Development, I believe very, very strongly, that is completely focused on the small-scale farmer and on pro-poor development will fail," he said. Wage incomes on commercial farms bring economic stability to families and communities.

Louis Sartor's 45-acre family-owned citrus farm survived a severe 10-year drought in Australia, thanks, in part, to a drip irrigation system that saved 3 million liters of water per hectare. That and other management changes significantly increased production. The farm recouped its drip irrigation investment within seven years. "Even though our enterprise is only small, we still survive because of technology," Sartor said. He also described the benefits of Australia's water reforms, including water trading, which gave farmers incentives to make water-saving changes to their farms. "We'd had maybe 10 or 15 years of debate on water with emotion and we got nowhere. So take the emotion out of water; trade it as a commodity," he said.

Watering lettuce using drip irrigation

Two Nebraska farmers – Jon Holzfaster of family-owned Holzfaster Farms and Jim Pillen, president of Progressive Swine Technologies (PST) – both described the yield- and water-saving benefits of center pivot irrigation. Holzfaster said he grew up observing irrigation become more water- and energy-efficient. Evolving tillage practices also resulted in tremendous water savings and erosion control. "We try and do whatever it takes to operate as efficiently as possible," Holzfaster said. Pillen's corn and soybean production is now part of a cycle that raises 1.25 million pigs annually. PST's efficiency comes from harvesting the manure to use as crop fertilizer. "Every drop of water we take up goes through a pig, and we put it back on our cropland to grow more crop. … It's totally contained." His operation also uses center pivots with drop nozzles, which reduce evaporation and runoff.

In the Clarksburg Wine District of California, Craig Kirchhoff of KFI West grows chardonnay grapes on 35 acres of flood-irrigated land and on another 65 acres using drip irrigation. Wine grapes are sensitive to overwatering, and because wine depends on high-quality grapes, precise timing and water amounts are critical. "Drip irrigation gives me so much flexibility in the vineyards," he said. "It's a comfort to be able to walk out and push a button and know that every vine in that vineyard in five minutes is getting water, if that's what it needs." It also reduces water use by 50 to 70 percent.

California's High Stakes Challenge

California's struggle over the Sacramento-San Joaquin Delta illustrates the problems many communities worldwide face as climate change and water demands escalate, said moderator Ann Bleed of the University of Nebraska–Lincoln (UNL). The Delta, home to an extraordinary biodiversity of wildlife, also provides freshwater for two-thirds of Californians and most of the state's farmland. Today, both the ecosystem and water supply are at risk as urban populations grow, climate change affects precipitation and fish populations collapse. For decades, water users have battled unsuccessfully over how to meet expanding urban and agricultural water requirements, while preserving critical habitats.

California's San Joaquin Valley

Panelists, representing different interests, described the challenges that make the Delta so intractable. Much discussion focused on disagreements over science and how to proceed in the face of risk and uncertainty. While Daniel Dooley of the University of California and Steve Thompson, formerly of the U.S. Fish and Wildlife Service, believe an adaptive management strategy would soften risks and allow a flexible path forward, Jason Peltier of the largely agricultural Westlands Water District said he believes an adaptive process isn't feasible. However, panelists agreed that strong government leadership is missing.

Thompson said he worries that without a long-term solution, Californians eventually will abandon the goal of conserving habitat.

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"If it fails, it's something that wakes me up in the middle of the night," he said. "We're much better off to do conservation ahead of time, over a 50-year period, than to face that war, from my perspective."

Roger Patterson of the Metropolitan Water District of Southern California said that most Californians remain unaware of the problem's gravity. Raising awareness is critical, although getting people to care is difficult.

Harvesting wheat near Grant, Neb.

Lessons from Ethiopia

In a case study panel focusing on Ethiopia, panelists blamed the country's climate variability, particularly droughts, for its stagnant agricultural productivity, reliance on food aid and lack of socioeconomic development. Irrigation, they agreed, is the key to increasing productivity and boosting economic growth. Several panelists described the tremendous potential of Ethiopia's surface water and groundwater supplies, which studies indicate could irrigate 10 times more land than current levels. The country, however, hasn't invested in water infrastructure due to lack of finances, specialized labor skills and technological and research capacity, among other problems. Kindie Tesfaye, a dean at Haramaya University, said Ethiopia's higher learning institutions haven't provided necessary capacity building. But recent expansion in higher education represents a major opportunity, and institutions should take advantage of the government's and donors' renewed interest in agricultural investment.

Several projects demonstrated other opportunities. Assefa Kumsa, general manager of Oromia Water Works Design and Supervision Enterprise, described surface water and groundwater irrigation projects that have brought food security to people living in the region, which suffers frequent, severe droughts. But until Ethiopia quantifies its water resources, irrigation planning remains challenging, Kumsa said. Robert Yoder, an International Development Enterprises consultant, described the company's pilot project that trains hand well drillers. Hand wells offer another opportunity to bring irrigation to smallholders while also creating small business opportunities for drillers. Mapping shallow groundwater resources and providing micro-credit financing are critical to making hand-drilling irrigation feasible, he said. Yitbarek Wolde-Hawariat, vice president for research and community services at Wollo University, also discussed opportunities for rainwater harvesting. In areas with sufficient rainfall, farmers benefit. However, among other challenges, lack of rainfall limits the usefulness of rainwater harvesting in other areas.

Technology alone won't solve these complex issues, said UNL soil scientist Martha Mamo. Incorporating social science research to understand the challenges farmers and others face is critical to devising appropriate solutions. Mamo, UNL anthropologist Shimelis Beyene and UNL graduate student Annie Cafer described their research, which integrates physical and social sciences and

"If women were the leaders in agriculture and livestock-raising and they took decisions about water for food, would the debate be different?"

reveals how differently water affects even adjacent communities, particularly those that irrigate and those that do not.

Closing Panel

The conference concluded with a panel discussion focusing on critical issues and recommendations for the Daugherty Institute. Panelists agreed that two consistent messages emerged during the conference: the need for partnerships and the importance of engaging the world's policymakers to promote agricultural support, to articulate critical issues and to help policymakers make sound decisions. Mick Mwala, a dean at the University of Zambia, emphasized the need to bring together diverse strengths but cautioned that partners from developing countries, which are disadvantaged, should be engaged throughout the process.

Technology must be adopted in poor countries, said both Nebraska farmer Eugene Glock and Valmont Industries Inc.'s senior vice president Robert Meaney. Farming is a business, no matter how small the farmer's land holdings, Meaney said. "The people who can make it into a business, those are the people who should go into farming and should become the people who build the [agricultural] sector," he said. But he and Glock acknowledged that people displaced by technology and enlarging farms remains a significant problem. Glock said, "I think that's a challenge that has not been addressed adequately yet. And when it is, we may see greater acceptance of the methodology that is available out there to address this food problem."

Moderator Prem S. Paul, UNL vice chancellor for research and economic development, said that incorporating the social sciences will be critical to change behavior in developing countries and encourage technological adoption.

Simi Kamal, chair and CEO of the Hisaar Foundation in Pakistan, stressed the need to involve marginalized people, including women, in future discussions. "If women were the leaders in agriculture and livestock-raising and they took decisions about water for food, would the debate be different?" She urged participants to consider agriculture as a component of a larger ecosystem. For millions worldwide, food security and a dignified life depend on environmental entitlements, something that must be considered when taking water from commonly owned or accessed water resources. "Crucially, we must address the issue of power," Kamal said.

Woman sifting grain

Introduction

The 2011 global conference, Water for Food: Paths to Solutions, honored Robert B. Daugherty, founder of Valmont Industries Inc., who died in November 2010, leaving a legacy of agricultural innovation and dedication to finding solutions to the challenge of growing more food with less water. When announcing his generous $50 million founding gift in 2010 to create the Robert B. Daugherty Water for Food Institute at the University of Nebraska, Daugherty said he envisioned an institute 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 gift recognized the university's long history of research leadership in water, agriculture and natural resources and its willingness to share that knowledge not only with Nebraskans, but with the rest of the world. The annual Water for Food conferences are one way to engage with, and learn from, others who bring decades of experience and perspectives from many disciplines and cultures.

Water for Food: Paths to Solutions explored the science, technology, policy and education resources necessary to meet the global challenge of doubling world food production with limited water resources. This interdisciplinary, multiple-stakeholder conference brought together more than 450 people from 24 countries and included agricultural producers, scientists, scholars and leaders from academic institutions, business, government and nonprofit organizations. Recognizing that the global community is at a precarious point as food needs increase while water remains scarce, participants shared their concerns and questions, ideas and solutions.

This year, the conference highlighted specific examples from programs and groups working to solve water and agricultural deficiencies in their areas. Speakers shared both encouraging advances and challenges to overcome. Leading off that effort in the opening keynote session, Jeff Raikes, CEO of the Bill & Melinda Gates Foundation, led a discussion with Kebede Ayele, Ethiopian country director of International Development Enterprises, and Soumen Biswas, executive director of India's Professional Assistance for Development Action. Each discussed his organization's approach to lifting rural farmers out of poverty, the challenges each organization faces, and what more is required. "We need to think about how we can have more affordable solutions for these smallholder farms," Raikes said.

Preparing a maize plot for planting

The conference included plenary and technical sessions as well as panel discussions that included leading industrialists, agricultural producers, representatives from California's Delta region, and experts working in Ethiopia. In Chapter 1: Viewpoints on Water for Food Challenges, six plenary speakers discussed future threats to water resources and potential solutions for maximizing their use. They included Anil Jain, managing director, Jain Irrigation Systems, India; Anders Berntell, executive director, Stockholm International Water Institute; András Szöllösi-Nagy, rector, UNESCO-IHE Institute for Water Education; Pasquale Steduto, Water Unit head, Food and Agriculture Organization of the United Nations, and Julia Bucknall, Water Department sector manager, World Bank.

Four panel discussions highlighted important differences in perspective among experts and stimulated much audience participation. The summaries are in Chapter 2: Paths to Solutions. The Industry Leaders Panel engaged people from biotechnology, irrigation and agribusiness firms in a debate about industry's role not only in advancing technology, but more controversially, in contributing to public-sector development. A View from the Field brought together a varied group of agricultural producers from Kenya, Australia, Nebraska and California to describe advances and challenges in water management. California's High Stakes Challenge, a panel discussion between divergent stakeholders in the hugely productive Sacramento-San Joaquin Delta, demonstrated how intractable water issues can become and underscored numerous obstacles to resolution. Lessons from Ethiopia described the problems and advances being made to increase irrigation and agricultural production in this African country that has long suffered droughts and malnutrition.

Three technical sessions featured presentations and discussions from leading scientists in the global community focused on areas central to the challenge of growing more food with less water, including Quantitative Food Security: Yield Gaps, Water and Nitrogen Productivity; Maximizing Water Use Efficiency in Agriculture; and Evaluation of Aquifer Resources in Sub-Saharan Africa. Abstracts from these sessions are available in Chapter 3: Scientific Sessions.

In the conference's closing session, panelists highlighted critical issues raised during the conference and provided recommendations for the Daugherty Institute. From their diverse perspectives in academia, industry, the nonprofit sector and agricultural production, panelists discussed technology adoption in developing countries, the role of women and other marginalized players and the need to engage the world's policymakers. Chapter 4: Thoughts for the Water for Food Institute includes a summary of this discussion.

The panelists agreed that two consistent messages emerged from this year's conference: the need for partnerships and the importance of focusing on and improving public institutions. These components, as well as technological advances and increasing global educational opportunities, are critical to solving the challenges in water use and agricultural production. The goal of the Robert B. Daugherty 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.

Viewpoints on Water for Food Challenges

1

Speakers

Will There Be Enough Water to Feed the World in 2050?

Anders Berntell
Executive Director, Stockholm International Water Institute

Anders Berntell described the challenges and opportunities of ensuring sufficient global water availability to feed the world in 2050.

Anders Berntell

When acknowledging future water challenges, it is important to consider the diversity of water uses throughout the world, he said. In Europe, households use the most water, with relatively little going toward agriculture, while in other regions of the world, agriculture uses the most water. Differences also exist within regions. Many countries, particularly in Central Africa, the Middle East and Southeast Asia, use more than 90 percent of available water for irrigation. However, agriculture accounts for 70 percent of global water use. In the hydrologic cycle, 40 percent of rainfall returns to the sea via rivers or by passing through the ground. The other 60 percent returns to the atmosphere. Of that 60 percent, 6 percent comes from irrigated agriculture, 16 percent from rainfed agriculture, 15 percent from other land cover and 63 percent from forests.

Challenges

Berntell detailed three challenges to maintaining enough water for agriculture. The first challenge stems from a growing world population that consumes more food – requiring a bigger water footprint, the total volume of freshwater needed to produce goods and services. The estimated 9 billion people who will inhabit the planet by 2050 also will have greater purchasing power, creating more demand for water, food, biofuels and other resources. These consumption trends will drive production.

The rate of global water consumption is double the world's population growth rate, predominately due to increases in agricultural water use. Each person uses 250 liters of water daily for hygiene, cooking and cleaning. However, diets average 3,500 liters per person. "This is the hidden water footprint behind our daily diets," Berntell said, "and that water, of course, has to come from somewhere, the river basin or an aquifer."

Country wealth greatly affects dietary water requirements. Countries with a higher gross domestic product, such as the U.S. and Norway, have higher dietary water requirements because inhabitants consume more animal calories. People in developing countries need more protein, Berntell said, and will want more animal protein in their diets as their countries develop.

Although some scientists in the 1970s predicted world hunger would be eliminated within 10 years, the level of undernourishment has grown substantially, from 825 million undernourished people to more than 1 billion in the last 15 years, despite increased agricultural production. At the same time, obesity rates have increased, and not just in developed countries.

Based on assumptions regarding the global scale for economic growth, as countries' GDPs expand, the water requirement to feed the world in 2050 will increase 80 percent. After adding fiber production, household and industrial uses and biofuels, which some believe may require the same amount of water as food production, is this future water equation achievable? Berntell asked.

A second challenge he described lies in the limited water resources available to meet future demand. Many parts of the world are water stressed while others suffer economic water scarcity, in which countries have enough water but lack the economic resources to use it productively. Many areas also suffer from the environmental consequences of water over-abstraction that threaten fisheries and ecosystem functions, such as filtering nutrients and preventing or reducing the effects of floods and droughts. Climate change also will profoundly affect water availability; however, predictions suggest population growth will, on average, have a greater effect, Berntell said.

At the river basin level, analyzing cumulative river withdrawals and water volume helps determine the water volume annually available to each person. Most river basins have both low consumptive stress and abundant water levels, like the Niger, or suffer both over-abstraction and water shortages, like the Nile and Rio Grande. A few, however, like the Colorado River Basin, still have sufficient water levels but suffer from over-abstraction and restricted environmental flows.

Agriculture along the Nile River in Egypt

Speakers

> *"Are we going to become much more effective when it comes to utilizing the water resources that we have, or are we going for more supply to safeguard the level of use that we have today?"*

Adding projected 2050 population growth to the analysis demonstrates that most river basin systems will face severe reductions in available water. For example, the Niger will move from about 300 cubic meters per person per year to below 100 cubic meters. Several river basins in India will be similarly strained. By contrast, China's population control measures will allow river basins to remain unchanged. And in some African river basins, such as the Okavango, water will become more available due to negative population growth.

To maintain water availability over time, managing supply is an option, though expensive and deleterious to downstream ecosystems that also require water. "This is the balance that each of those river basins needs to figure out," Berntell said. "Are we going to become much more effective when it comes to utilizing the water resources that we have, or are we going for more supply to safeguard the level of use that we have today?"

In some river basins, such as the Colorado, the Murray-Darling and the Nile, water is already unavailable to further development. Many other areas are overdrafting groundwater. If the present trends continue, two out of every three people will live in water-stressed conditions by 2025, Berntell said.

The third challenge is the dramatic effect climate change will have on the world's water availability, including changes in precipitation and river flow. The net effects of climate change on agriculture yield vary by region. North America, for example, will average a 1 percent decline, Sub-Saharan Africa a 15 percent decline and South Asia an 18 percent decline.

Opportunities

Despite these challenges, Berntell expressed optimism that countries can increase water productivity and efficiency and that advances in agriculture will lead to greater production using less water.

One opportunity for maximizing water productivity is to reduce loss of food from "field to fork." Although estimates differ, newspapers have reported that Swedes and Britons throw out 25 to 40 percent of the food they buy and that India wastes $100 billion in food annually. According to the Food and Agriculture Organization of the United Nations (FAO), the world annually produces enough food to provide every person with 4,600 daily calories, but loses 600 of those calories to post-harvest losses, another 1,700 calories to animal feed and 800 calories at the distribution and household level. In total, about 50 percent of what is produced is lost.

Addressing food prices would curb losses. Although prices have increased in the past decade, today's prices are still low relative to historic levels. Between 1960 and 2000, food prices declined 50 percent. "What other commodity could we

afford to lose 50 percent from production to consumption?" Berntell said. "I'm not arguing that we should dramatically increase food prices … but it's something that needs to be looked upon."

Social forces also affect the water footprint. Massive urbanization and increasing wealth in many regions are altering food preferences, particularly the demand for grain-fed meat, which requires more water to produce.

"We cannot feed the world on hamburgers and steaks. There has to be a balanced diet in order to be able to feed the world with the constrained water resources that we have globally."

Another opportunity involves increasing trade and shifting production of food that requires more water during the growth cycle to regions with greater water resources. Given the varying effects of population growth and climate change worldwide, Berntell said, "I think it's clear that trade in food products will have to play a very important part of the total solution in the future." Water trade for food production is already happening. For example, North America is a huge net exporter to other parts of the world. Australia, an extremely water-scarce country, also sends large amounts of water to other regions through agricultural export. "That caused quite a lot of discussion there," he said, "but on the whole, I think that this is something that needs to be discussed internationally to a larger extent than what it is today."

Shipping carrots

Conclusion

Enough water will be available to feed the world in 2050, Berntell said. But agricultural water productivity must increase substantially, particularly in developing countries where much room for gains still exists, such as by reducing evaporation losses.

"We need also to consider and be aware of the water footprint of our diet," he said. "We have to reduce losses of food in the chain from field to fork. And, on a global scale, we cannot imagine that biofuels will be the solution to the global fuel crisis. And we have to use trade much more effectively as a policy instrument to address the future challenges."

Speakers

Agricultural Water Management in Developing Countries: Meeting the Competing Challenges of Food Security, Water Scarcity and Climate Change

Julia Bucknall
Sector Manager, Water Department, World Bank

Competing demands for water require difficult choices, including taking water from those who have it to share with others who don't. However, most governments have not confronted these enormous challenges, Julia Bucknall said. "If we don't do that, we're going to be in a worse situation later. That is the challenge of the next few decades." Bucknall described the difficulties of investing in irrigation in developing countries and how competing water demands must be considered when making decisions about irrigation investments.


Julia Bucknall

Confronting Realities

Irrigation greatly increases production. For agricultural production to meet future food demands, irrigation will be critical – even if it's done on a small scale, such as water harvesting. However, as a World Bank economist investing in irrigation for the past 15 years, Bucknall said she has found it difficult to prove that irrigation financed by the public sector is a good value for the money. "It might be, but it's difficult to demonstrate that, and I think we have to do a better job," she said. Project investments typically last five to seven years, and organizations conduct few long-term reviews to determine impact. While some projects are clearly successful, other reviews have failed to show clear economic rates of return, she said.

The World Bank spends about $5,000 per hectare on irrigation in developing countries. "We really should be generating more money with that, and we're actually not," Bucknall said, adding that in Australia and the U.S., the added value of irrigation is likely much higher. It's not easy to make the right irrigation investments and ensure they'll pay off because public-sector irrigation is put in place for social and legal reasons, such as land tenures, that create barriers and constraints that are difficult to overcome.

For example, despite the extremely high land and water productivity in the Nile Delta region of Egypt, the area's contribution to the country's gross domestic product is low because land is allocated in small parcels and many farmers don't use the latest technology. By contrast, in the West Delta irrigation area, people are using the latest technology to convert once unproductive land

into large plots of arable land. Today, West Delta farmers produce some of the highest-value crops per cubic meter worldwide, even though they occupy some of the least fertile land.

"We work with the middle people who have all the social constructs that make it so difficult to move up that value curve," she said. "They are behaving extremely rationally by not taking the highest productivity varieties and not making all the physical investments. And that's one of the reasons that irrigation investments are so difficult to give nice, big, high economic rates of return."

The World Bank also invests in irrigation through the local private sector and seeks to integrate private with public sector concerns, Bucknall added. "We're not always concerned with financial rates of return," she said. "Often it's economic rates of return so that the overall economy is better off, including some of the more intangible things like social and environmental issues where the evaluation is difficult."

Asked whether it's possible to compare the social benefits of irrigation with market benefits, Bucknall replied that when spending so much money on irrigation, and when the resource has so much implicit value, there may be other ways to generate that social benefit. "The market won't separate the social benefits and the food security benefits," she said.

Making Irrigation Work

"In my view, my organization and governments that work in developing countries need to think very hard about irrigation strategies," Bucknall said. For the past 40 years, the World Bank has primarily worked on moving water from dams to farms, a difficult job that entails making sure tail-enders (often poor farmers whose land is near the canal's end) receive their share, that farmers pay for it and that the investments are maintained.

That approach is now limiting, she said, and the World Bank must look backward at the competing demands for water as well as forward to smallholder farmers' market access. Looking backward, people must think about water allocation more broadly. Bucknall said she once visited a North African country that was asking the World Bank for $200 million to invest in irrigation systems to supplement its highly variable rainfall. She asked officials how much water the country would allocate to irrigation at the end of the investment's useful life, given that its cities are growing and that its water basins are closed. Her question was met with silence, she said, because the people who make irrigation investments don't have those answers. "We need to have that conversation, in my opinion, much more strongly."

"I believe it is a huge mistake to put in place policies and technologies that are not compatible with the institutional capacity and political will of the country in which they're operating."

Looking forward in the process, the World Bank also is bringing farmers together to contract with supermarkets and product manufacturers so they can compete with larger-scale producers. "And so, in a sense, our irrigation investments have

Speakers

to get a lot more complicated," Bucknall said. "But if we make them more complicated, I believe we can make them more successful and more productive and more equitable."

When asked if the World Bank intended to advance irrigation in Africa, given irrigation's critical role in Asia's Green Revolution, Bucknall responded that the agency has an ambitious African irrigation policy. But she believes it will be difficult to achieve. "If you don't have access to markets, you will be growing sugar beets and wheat with your $5,000-a-hectare investments, and that's not necessarily the best thing you can do with that water, given all the competing demands," she said. "I think it's important to do more irrigation in Africa … but linking it to the market, recognizing the value of both the water and the infrastructure, is going to be absolutely essential. And then the competing demands are going to be huge."

New technology will help build the forward link between farmers and markets, and the backward link between farmers and water allocators, Bucknall said. For example, in India, cell phones allow farmers to access markets more quickly, and other technologies allow water planners to examine water productivity and allocation issues.

Though looking forward and backward makes the job more complex, Australia demonstrates that transformation is possible, she said. Driven by drought, the government instituted reforms that established adaptive regulatory regimes, water rights trading and commissions with the

Wheat harvest

authority to cap withdrawals. Though the drought significantly reduced water availability, water productivity increased.

Australia could not have accomplished that transformation without strong institutional capacity, she said. Institutions are strengthened by action, but investing in institutions works only when they want to improve. "I believe it is a huge mistake to put in place policies and technologies that are not compatible with the institutional capacity and political will of the country in which they're operating. I believe it will worsen the situation," Bucknall said. "We have to be also cognizant of the capacity of the institutions with which we're dealing."

Global trade policies also should acknowledge that small countries don't trust the food trade system, she said. Most countries are net food importers, and poorer countries that import most of their staple foods are vulnerable to food price spikes. While slight productivity increases in North America, Europe and Australia may provide enough food to feed the world, can it be distributed properly? "I think that's a big question and one that worries me," Bucknall said. "I think that we have to get the economics right and try to build irrigation systems for other reasons, given the competing demands for water."

Conclusion

The world has enough water and technological innovation potential to meet food demands, Bucknall said. A less-discussed, but important factor is higher food prices, which should encourage farmers to adopt advances, as long as food prices aren't volatile.

"It's important to get it right and to make sure that we are trying to move ourselves to 110 percent of where we are now, not to 300 percent of where we are now … to think of the potential poverty implications of getting it wrong," she said. "The increase in prices probably will help from a farming perspective, but there will need to be adjustments in the social welfare perspective to make up that for that."

Speakers

Transformative Impact of Drip Irrigation on Small Farmers

Anil Jain
Managing Director, Jain Irrigation Systems Ltd., India

Anil Jain shared his vision for transformational change of Indian agriculture and described Jain Irrigation Inc.'s experiences and successes introducing smallholder farmers in India to drip irrigation, agronomic management practices and other strategies. With more than 1 billion of the world's population connected to smallholder agriculture, Jain said, the potential impact of drip irrigation is enormous.

Anil Jain

Indian Agriculture

India has the second-largest amount of arable land in the world, making it a land of plenty, in one sense. The total area under cultivation – almost 140 million hectares – is significantly higher than in many other countries. Yet agricultural productivity is one-third to half that of developed countries, largely due to lack of mechanization and smaller farm sizes. The average landholding is 1 to 1.5 hectares, indicating that even commercial farms are relatively small. In addition, half of India's agriculture is rainfed. With 60 to 70 days of rain a year, farmers who have rainfed land produce just one crop annually.

Although India's gross domestic product is growing about 10 percent annually, agriculture's share is not keeping pace. Comprising half of India's GDP about 40 years ago, agriculture now accounts for just 18 percent of total GDP. Jain predicts that without proper oversight, agriculture's share could drop to 12 percent. Because 60 percent of India's 1.2 billion population depends on agriculture, the decreasing share of GDP growth will cause huge income inequalities. In the early 1960s, India's Green Revolution achieved spectacular results. By focusing on increasing irrigation and fertilizers, India went from depending on imported food and food aid to growing 230 million tons of food grain. Yet today's farmers face many obstacles to increasing their productivity and incomes.

Fertilizer use and over-irrigation have made once-productive lands much less so, salinity is devastating large parts of northern India, and groundwater levels are dropping. In some places, farmers must dig wells as deep as 700 feet to find water for irrigation. In addition, India's small farm sizes limit mechanization. While a large labor force once provided sufficient workers, new government programs guaranteeing work on public projects have created farm labor shortages. University Extension programs and

"We believe that the evolution of our business model is creating evolution for small farmers. With small ideas, you can create big evolutions."

financial services also are lacking. Some farmers borrow from moneylenders at an interest rate of 4 to 5 percent per month, and debt has contributed to high suicide rates among India's farmers.

While productivity is decreasing, higher population growth and greater demands for protein in urban areas will require food production to nearly double to about 500 million tons over the next 20 to 30 years. However, the area under cultivation will remain the same or decrease as industrial and urban growth continues to take over existing farmland.

The answer, Jain said, lies with India's rainfed agriculture, even though it currently produces just one crop per year. India must double the total land area under irrigation to meet future food requirements. The water deficit will be enormous, he said. The country's future water requirements are predicted to rise to 1,200 billion cubic meters from today's 700 billion cubic meters. Irrigation uses 83 percent of India's water, and water wars between Indian states have already begun. "The scenario is quite scary," Jain said.

Solutions

Doubling irrigation can be achieved more sustainably with micro-irrigation systems, Jain said. Drip irrigation technology delivers water, fertilizer and nutrients to the plants when and where they need it, resulting in water savings, higher productivity, less fertilizer and lower energy usage.

"We are getting great results for the small farmer," Jain said. "But is that enough, just delivering water in the right manner to the plant? We don't think so. If we really want a transformational impact, I think you need to look at the entire agriculture (industry) in a holistic manner."

With this comprehensive focus, Jain Irrigation developed an integrated model, which in addition to manufacturing drip irrigation products, also provides farmers agronomic management support and a market by buying some of the crops. To complete the self-sustaining agri-cycle, Jain Irrigation will soon launch a rural agri-finance company with reasonable interest rates.

One example of the company's agronomic support involves increasing plant density. For centuries, farmers have planted about 40 mango trees per acre. After the company proposed planting 600 trees per acre, farmers had tripled their income by the second year. Ultra-high density planting requires more irrigation and nutrients. Where groundwater is scarce, the most effective solution is rainwater harvesting.

Jain said although India's record for delivering on large infrastructure projects, such as dams, is disastrous, effectively storing water directly on the small farm may allow farmers to produce two or three crops after the rainy season. "And that is the difference between poverty and sustenance."

Speakers

Different areas often require different solutions. For example, in the North, farmers deal with up to eight months of severe weather. For them, greenhouses and other forms of controlled agriculture provide opportunities to expand production. Although greenhouses are considered expensive, the company has built 17,000 small ones in Himachal Pradesh state.

To encourage farmers to invest in these solutions, Jain Irrigation dedicates resources to training and capacity building. In 2010, more than 250,000 farmers received training in their villages or at the company's 3,000 acres of research farms. In the past 30 years, the company has reached nearly 5 million farmers, and nearly 2.5 million have adopted its technology. For the past 20 years, the company has concentrated on farmers with access to water, converting flood irrigators to drip irrigation. But how can the productivity of dryland farmers be improved?

To help answer that question, the company has developed models for harvesting rainwater and creating an energy source. It is developing small-scale, solar-powered drip irrigation systems in which rainwater is harvested and pumped via a solar water pump. With a $600 to $700 one-time investment, the farmer receives solar pumps, solar panels and a drip irrigation system that will last seven to 10 years and can double or triple production.

Benefitting Farmers

Jain believes that with the right technology and knowledge, farmers can increase income from an average $100 to $200 per acre to $1,500 per acre. "That is what I call our transformational impact," Jain said.

Jain Irrigation has documented millions of cases of the enormous impact drip irrigation and other agricultural improvements have had on farmers' lives. He cited numerous examples.

- A chili farmer previously producing 12 tons per acre with flood irrigation now produces 30 tons per acre with drip irrigation for a net income of $3,000.
- Working along the entire production chain for onions – from seeds, planting method, irrigation and fertilizer to purchasing onions back from the farmer – the company has increased production from 6 tons per acre to between 9 and 14 tons per acre.
- Sugarcane producers are setting world records. One drip irrigator produces 130 tons per acre compared to the national average of 40 tons per acre.
- Cotton farmers, previously picking just once per year, are now picking cotton up to four times annually with drip irrigation.
- Yield increases also are happening in tomatoes, French beans, capsicum, potatoes, pulses and other fruits and vegetables.

The company also is tackling rice, a large water consumer. India has 43 million hectares under rice cultivation, and Jain believes rice production can be increased while using 70 to 80 percent less water.

Research plays a critical role in improving rice and other crop cultivation, but public research has not achieved many results in India, Jain said. Most new crop varieties, for example, have come from private research. The company is collaborating with international organizations, such as the International Rice Research Institute

Installation of a drip irrigation system

(IRRI) and the International Maize and Wheat Improvement Center (CIMMYT), to research methods of growing products more sustainably.

Conclusion

Jain emphasized the need to think beyond technology to a more holistic approach that considers smallholders' incomes while also maintaining long-term sustainability.

The company is working in a few African countries, applying lessons learned in India. "We think our experience and learning in India can be duplicated in Africa," Jain said.

With 7,000 employees and 2,500 dealers, Jain Irrigation has created employment, directly or indirectly, for nearly 200,000 people in rural India and positively affected the lives of about 30 million people, Jain said. He anticipates the company could influence the lives of 300 million to 500 million people in the future.

"We believe that the evolution of our business model is creating evolution for small farmers," Jain said. "With small ideas, you can create big evolutions."

President's Welcome

Making the Biggest Impact on the Areas of Greatest Need

James B. Milliken
President, University of Nebraska

The Robert B. Daugherty Water for Food Institute has come together quickly, said James B. Milliken. In 2009, the inaugural Future of Water for Food conference convened with the intent of assembling experts from around the world to consider whether a new global water institute was a good idea and how it would work. "We took to heart the advice we received at that first conference, and we've continued to meet with and listen to experts from across a broad spectrum of disciplines," Milliken said. "At every turn, we were greatly encouraged by the potential that others saw for the University of Nebraska (NU) to assume a leadership role in building an institute that would focus its attention on growing more food with fewer resources."

James B. Milliken

The Daugherty Institute is now established with a clear agenda, has developed international partnerships with the private and government sectors and will soon hire a new director*. "For that we owe an enormous debt of gratitude to Bob Daugherty and the Daugherty Foundation," Milliken said. Daugherty, a pioneer in modern agriculture, founded Valmont Industries Inc., the world's largest center pivot irrigation company. His efforts have resulted in tremendous yield increases and benefitted food production worldwide.

Daugherty also saw NU's potential to play a leading role in alleviating world hunger. In 2010, he gave the university a $50 million gift to form the Water for Food Institute, with the mission of providing research, education and policy analysis related to agricultural water needs. He passed away in November 2010 at age 88, and the institute was named in his honor. "It's a fitting tribute to a man of great vision, foresight and generosity," Milliken said.

He credited Mogens Bay, Valmont CEO, as a leading inspirational figure in the institute's creation. Bay suggested meeting with Jeff Raikes, CEO of the Bill & Melinda Gates Foundation, whose encouragement also was a key reason for the institute's early success. "It's gratifying to see how quickly this conference has matured and grown, bringing together the right mix of people we envisioned two years ago: research scientists,

"Today and beyond, we have a great opportunity to collaborate, to solve one of the great challenges we face."

engineers, agronomists, producers, leaders in business, government and private foundations," Milliken said.

The Daugherty Institute is focusing on making the biggest impact on areas of greatest need, such as education and collaboration. At the 2011 global Water for Food Conference, the institute signed a memorandum of understanding with UNESCO-IHE Institute for Water Education in Delft, the Netherlands. After meeting with IHE officials, Milliken said, "it quickly became apparent that our expertise relating to water needs of production agriculture could provide an essential piece of a larger puzzle."

The partnership establishes an exchange program in which NU students will benefit from renowned IHE programs, such as water management and engineering, and IHE students will have the opportunity to use Nebraska agriculture and the High Plains Aquifer as their field laboratories. Other educational commitments include Daugherty fellowships and scholarships, attracting eminent scholars to NU, and developing new study programs in critical areas of water resource management.

Research also is a key focus, and the institute's highest priorities are initiatives in yield gap analysis, aquifer characterization and efficient water use in irrigation.

"One of the important lessons that's been reinforced over the past two years is that the challenges associated with water are so numerous that we can't expect to solve them all," Milliken said. But the Daugherty Institute, envisioned as a distributive center, can help incorporate key segments – the private sector, universities, governments, foundations, agricultural producers and others – into a network of worldwide knowledge dedicated to finding solutions.

The institute's partnerships include, for example, collaborations with the M.S. Swaminathan Research Foundation in India to conduct a conference on sustainable management of water resources; with Brazil on policy issues through the World Water Forum's regional focus on the Americas; and with Chinese researchers on yield gap research that has doubled maize production.

The Water for Food Conference also has been designated an official preparatory event for the sixth World Water Forum in France in 2012.

"Today and beyond, we have a great opportunity to collaborate, to solve one of the great challenges we face," Milliken said. "And I'm confident that this conference, and those that follow, will have important consequences in developing mutually beneficial collaborations, identifying common interests, complementary expertise and talent, helping to prioritize areas for work and investments, and effecting long-term efficient use of water for food throughout the world."

**Roberto Lenton's appointment as director of the Daugherty Institute begins Feb. 1, 2012.* *Read more about Lenton on Page 107.*

Chancellor's Welcome

Partnerships Key to Solving Water for Food Dilemmas

Harvey Perlman
Chancellor, University of Nebraska–Lincoln

It wasn't until humans freed themselves from the all-consuming search for food that they distanced themselves from lower forms of animal life and developed the modern world, Harvey Perlman said. Although many people in the developed world are fortunate to spend little time and few resources feeding their families, in many parts of the world the struggle to feed oneself and one's family remains a full-time job, and given food's central role in sustaining life, a full-time passion.


Harvey Perlman

"It can truly be said that we cannot unlock the human potential without solving the challenges of food," Perlman said.

Concerns about food security increasingly provoke global events. While some governments have failed to ensure food security or are at risk of failing, others recognize that satisfying this basic human need is essential and are developing policies to secure food supplies at reasonable costs. Other challenges include the protestations and policies surrounding transgenic food; the importance and immutability of freshwater supplies; climate change and its uncertain effect on food supplies; the incredible array of, and in many cases, the dysfunction of, government policies that often discourage food production; the general public's disinterest about where their food comes from and how it's produced, and, most importantly, the interlocking nature of global food markets in which the success or failure of one country's efforts directly affects the rest of the world.

"It can truly be said that we cannot unlock the human potential without solving the challenges of food."

The Robert B. Daugherty Water for Food Institute's central concept is to leverage the resources of a comprehensive research university and to work with partners throughout the world to address these issues. The University of Nebraska–Lincoln (UNL), as the flagship research campus of the University of Nebraska (NU) system, has received strong support to pursue this mission, Perlman said. "Our long-standing commitment to research, education and outreach activities in water, in agriculture and natural resources management, in techniques to maintain high

crop productivity, while preserving water and soil resources, have well served Nebraska's agriculture and the world."

UNL is prepared to martial those resources, as well as its expertise in the social sciences and humanities, law and engineering, to address these complex issues, in collaboration with the other NU campuses.

"And, most importantly, we are open to partnerships with others necessary to get the job done," Perlman said. One of this country's fastest-growing universities in research, UNL is developing the Nebraska Innovation Campus (NIC), a 232-acre research park with a primary focus on food, fuel and water. NIC is a public-private partnership, where private companies partner with the university to innovate and develop talent.

"We look forward to the day in the not-too-distant future when the Daugherty Institute will be housed on the campus as an attraction to other public and private organizations working in these areas," Perlman said.

Illustration of two buildings planned at Nebraska Innovation Campus

Keynote Dialogue

Water and Food Security: A Firsthand Perspective

Jeff Raikes
CEO, Bill & Melinda Gates Foundation

Kebede Ayele
Country Director, International Development Enterprises (IDE), Ethiopia

Soumen Biswas
Executive Director, Professional Assistance for Development Action (PRADAN), India

The Bill & Melinda Gates Foundation considers securing water for food to be one of the greatest challenges of this century, Jeff Raikes said. To provide a firsthand perspective of the problems in overcoming this challenge, Raikes, in his third year speaking at the global Water for Food conference, invited Kebede Ayele and Soumen Biswas to join him to discuss their programs and answer audience questions. Both have more than 20 years of experience in the development sector.

Kebede Ayele is the Ethiopian country director for International Development Enterprises (IDE), a nonprofit corporation that creates income opportunities for poor rural households in the developing world through micro-irrigation development and other interventions. Raikes said he appreciates how IDE bootstraps technologies onto small businesses, setting them up to create scalable, sustainable solutions to alleviate poverty. He considers IDE a catalyst for lifting poor people out of poverty by providing affordable solutions.

Soumen Biswas is executive director of Professional Assistance for Development Action (PRADAN), a voluntary organization with a mission of enabling poor rural families in India to live a life of dignity through poverty alleviation and rural development.

In Ethiopia and India, farmers comprise a large percentage of the population – 85 percent and 65 percent, respectively. Ethiopia's 65 million farmers and India's 120 million farmers far outnumber the fewer than 1 million in the U.S.

Like most farmers in the developing world, Ethiopia's and India's farmers are poor and work small acreages. Raikes said between 1.1 billion and 1.3 billion people in the world live in extreme poverty, defined as income of $1 a day or less. About 70 to 75 percent of them live in agricultural areas and depend on subsistence farming.

Ayele compared the poor subsistence farms IDE assists and the Nebraska farms he toured during his visit. Farmers everywhere work hard and face market volatility and weather variability, he said, but the differences between them are vast. While Nebraska farmers may have GPS-equipped tractors and mechanized farming systems, Ethiopian farmers use oxen and plows. Roads may be in such disrepair that they're unable to travel even by donkey cart. Ethiopian farmers also have

Kebede Ayele, Soumen Biswas and Jeff Raikes

limited access to communication, irrigation and inputs. Seeds for high-value vegetable crops, for example, are either unavailable or too expensive, particularly given the lack of access to financial credit in Ethiopia.

IDE views farmers as customers, Ayele said. "We don't like the word *beneficiaries*. The connotation there is a recipient and a giver relationship. We are not givers. We create opportunities for them to prosper and get themselves out of poverty." By listening to customers, he said, IDE can offer products and services relevant to their needs and help them use their primary resources – labor, water and land – more productively.

IDE uses two key components: irrigation and market access. Because the biggest constraint to productivity is access to water, Ayele said, IDE designs and develops simple and affordable household irrigation systems. As a technology facilitator and design developer, IDE pays the cost of developing a product, such as a manual pump. It then works with the private sector to build a supply chain, training local manufacturers to make the pump. Farmers bear the purchase cost. But by adopting manual irrigation technology, farmers can transition into producing marketable high-value crops. IDE then connects them to profitable markets for their products.

PRADAN in India begins at a more basic level, Biswas said. If farmers view themselves as poor and lacking technical skills, it may prohibit them from entering the market or adopting technology. Altering their self-view through social mobilization

Keynote Dialogue

becomes a critical component in turning them into customers. PRADAN begins by building trust with farmers to more effectively provide them with services.

He said one successful service includes organizing small support groups of about 15 farmers, particularly women, who come together to discuss problems and solutions. Through these groups, participants slowly build confidence while taking on increasingly complex tasks. Eventually they have the confidence to negotiate with the market and local government officials or to understand new technology, Biswas said. Communities often identify water – normally either the inability to hold it or flooding – as their biggest challenge.

Raikes said, "We think technology is the magic answer but, in fact, it requires social mobilization, a change in mindset. It requires education to understand the financial benefits of the investments."

"If [farmers] get the opportunity, the right opportunity, they can lift themselves out of poverty very quickly."

Biswas said support groups become an important source of education. Members teach each other how to use or improve technologies. Yet education works both ways. Farmers also can advise researchers about what works and doesn't work, and how technology can be best adapted to their needs. Although farmers may be unable to read or write, PRADAN offers a practical form of education by demonstrating new technology and relating to farmers on their own terms.

Farmers weeding their crops

Ayele said he agreed that technology alone does not bring about change. While most of IDE's costs are related to development, it also works with farmers on technology adoption. "The first work is to change their mindset," he said. Most have never used irrigation or grown the marketable crops possible with irrigation. IDE must convince farmers that by investing in a treadle pump, for example, they can recoup their investment within six months and make an average $600 profit.

One audience member suggested that introducing technology often forces people off their land or to lose their livelihoods, a particular concern in countries where so many lives are tied to agriculture.

Raikes said, "Historically, countries that have exited from extreme poverty have done it through improvements in agricultural productivity," except for oil-rich countries. "But one of the implications of those productivity improvements is that labor is freed up from agriculture and becomes available to other industries."

"The importance of prosperity and wealth creation is key as a mechanism to address poverty."

He cited the U.S., where the number of farmers has dropped from tens of millions in the 1930s to a few million several decades later, and then to less than 1 million today.

"It's our belief at the Gates Foundation that what ultimately happens is that the improvement in agricultural productivity creates greater wealth within the economy and creates greater opportunity to add value in other industries. But that requires very careful planning and very careful thinking through of policy."

Biswas said in India, agricultural technology was introduced to produce more food for a growing population, but only farmers already producing marketable crops invested in it. The result was that poorer farmers had even less market power. PRADAN advocates for these farmers with the Indian government and asks farmers what technology they need to ensure that marginal households can produce their own food, Biswas said.

Similarly, Ayele said, by working with small-holder farmers, IDE gives them an opportunity to increase their productivity and their incomes. "We are making the rural life more attractive to them and creating a means of survival for them." He cited an example in Rift Valley, Ethiopia. Though the area has many lakes, farmers traditionally have been unable to afford irrigation pumps. Commercial farmers come in, rent the land, irrigate the crops and hire landowners as laborers. By offering smallholder farmers affordable irrigation technology, IDE gives them an opportunity to work and control their own land.

Ayele emphasized the need to relate to farmers as customers. "If they get the opportunity, the right opportunity, they can lift themselves out of poverty very quickly. That's what we have learned."

Raikes said prosperity, wealth creation and affordable technology are critical when addressing poverty. And technology should not be developed just for wealthy farmers. "We need to think about how we can have more affordable solutions for these smallholder farms. We need to understand how these farmers can have market access," he said.

Speakers

Sustainability Evaluation as Guiding Principle: Food Production in the Focus

Peter Saling
Head, Eco-Efficiency Analysis Unit, BASF, Germany

Evaluating sustainability has become an important component of BASF's decision-making process. The chemical company has conducted sustainability evaluations for more than 15 years and has completed 450 studies to date, Peter Saling said. He described the company's methodology and the benefits it receives.

Peter Saling

Evaluating Sustainability

Factoring sustainability into its business activities helps BASF reduce reputational risks and create value, Saling said. The company defines sustainability as an equal balance between economy, ecology and society. In agriculture, for example, sustainability ensures farming profitability, caring for the environment and meeting societal expectations.

To evaluate sustainability, BASF uses cradle-to-factory gate calculations that factor in both social implications and eco-efficiency analyses, which incorporate life cycle assessments, environmental impacts and economics, such as total cost of ownership. The environmental evaluation portion determines impact over the entire life cycle and examines energy and raw material consumption, emissions, toxicity, land use and risk potential, such as occupational diseases. The comprehensive analysis may show, for example, that a popular idea like recycling is less sustainable than an alternative if it requires more energy consumption to achieve.

A single study can generate 10,000 data points, but analyzing hundreds of graphs isn't useful for making decisions, Saling said. BASF normalizes the data to create an ecological fingerprint of alternatives. After adding societal factors, researchers determine an aggregate score of the environmental burden. Then, they integrate the costs of each alternative into an overall eco-efficiency portfolio. "In the end, you'll see in a very simple picture who's the best and who's the worst due to eco-efficiency in this system boundary," he said.

To illustrate the importance of sustainability evaluations on a company's decisions, he described an example in which BASF examined a company's vitamin B2 production. After a study determined a biotechnology process to be more sustainable

No-till corn

than its chemical process, the company closed the chemical plant in Denmark and opened a biotechnology plant in Korea. “It was kind of a mind change to say chemistry is not always the best thing,” Saling said.

In another example, the company studied Braeburn apple production. Although some consider buying food locally the more sustainable option, according to BASF’s study, sustainability depends on the growing season. It requires more energy to cool apples in storage for sale out of season than to transport apples that have been grown in season elsewhere, the study found. The company works with a German retailer to inform customers which apples are more sustainable at any given time.

In another study, the company determined that Headline® fungicide use in U.S. corn production improves eco-efficiency more than 5 percent.

Sustainable Agriculture

Sustainable agriculture encompasses not only green fields and bountiful vegetables, Saling said, but also biodiversity, education, health, crop marketability and water use, among many other factors. As BASF moved into agriculture, it developed a new tool called AgBalance, which maintains the company’s holistic view of balancing social, ecological and economic factors while encompassing agronomic specific characteristics.

AgBalance can cover many perspectives, from a specific Nebraska farm to an entire country. Studies can compare wheat production in Nebraska and Iowa, for example, or Brazilian and American production. Unlike a straightforward chemical process, Saling said, “the agro system is so complicated.” There isn’t a bulletproof method to raising crops, and every field has unique production needs.

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Water use is an important factor in agricultural sustainability. BASF uses many data measurements to determine water availability and withdrawal to derive a water stress index. Other factors integrated into the calculation include damage to ecosystem quality, resources and health, such as lack of freshwater for hygiene, spread of diseases, and malnutrition from irrigation shortage. Ultimately, these measures create a consumptive water use fingerprint.

To illustrate, Saling showed results comparing water consumption in cotton production in different countries. Plugging country-specific numbers into the water stress index formula demonstrated that India consumes the most water, while the U.S., as a whole, fares the best. In comparing water use, the results provide clear information.

However, water use is just one part of the sustainability evaluation, Saling said. If the question involves the sustainability of producing 1,000 T-shirts, other processes aside from water use in cotton production might compare differently in the final analysis, which must be considered.

This methodology produces a final socio/eco-efficiency score to clearly show the study's results. "And that's the thing you need for a decision-making process, because at the end, you cannot not decide," Saling said. "At the end, we want to have a final result based on a lot of statistical numbers and information."

Use of Sustainability Evaluations

BASF uses these sustainability evaluation tools to make strategic investment and technology decisions, as the vitamin B2 example illustrates. These tools also demonstrate product advantages to market to customers. Research and development also benefit by filtering ideas and research strategies early in the process.

Finally, the tools inform legislative decisions. In Europe, for example, a directive sought to maximize recycling old cars. However, a study determined that in a car's life cycle, 80 percent of the environmental burden comes from driving it, and just 5 percent from recycling. "It makes much more sense to optimize this step and have really high-functional materials and to make that better, [rather] than doing good recycling," Saling said. Based on that study, the European Commission reevaluated its legislation.

Biodiversity is a key component of sustainable agriculture.

Crop Water Productivity: Filling the Gaps

Pasquale Steduto
Head, Water Unit; Deputy Director, Land and Water Division,
Food and Agriculture Organization of the United Nations, Italy

A large gap between potential and actual water productivity exists in many areas worldwide, particularly developing countries. Pasquale Steduto addressed this and other important gaps involved in crop water productivity.

Pasquale Steduto

Terminology Gap

The research community tends to use the terms *efficiency* and *productivity* interchangeably, Steduto said. However, they have different meanings and contexts, and it's best not to use the term *efficiency* when discussing agricultural productivity, he said. Efficiency is still grounded in physical engineering, where the ratio of output to input has no dimensional units, and the theoretical limit is between zero and one. In addition, efficiency implies causality between input and output, which is incorrect related to production. Similarly, the term *water use efficiency* is also widely used but also not preferred because it doesn't fit the efficiency theory.

The Food and Agriculture Organization (FAO) advocates using the term *water productivity,* which has specific units (kilogram per cubic meter). Because it has no theoretical limit, Steduto said, water productivity cannot be called efficiency. In addition, no causality between input and output exists. Water productivity can be used as a ratio between beneficial output and water input in whichever unit applies to each. Most importantly, water productivity emphasizes the product, in contrast to efficiency, which emphasizes the process.

Confusion also surrounds the terms *efficiency* versus *saving,* Steduto said. At times, one can irrigate efficiently but not save water, such as when water saved through improved irrigation efficiency is used to expand irrigated land. Therefore, it's necessary to distinguish between the terms *consumptive* and *non-consumptive* water use, as well as *beneficial* and *non-beneficial* consumption.

Another source of confusion may exist when discussing irrigated versus rainfed systems. People may refer to improving the rainfed system, when in actuality the rainfed system has become an irrigated system. Some refer to a continuum between rainfed and irrigation, but a deterministic difference exists. Irrigation management allows one to intervene in both the amount and timing of water application. In a rainfed system, only the amount of water

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Installation of a subsurface drip irrigation system

applied pertains, as in conservation agriculture or aridoculture practices. "As long as the time is set by the climate, you are not in an irrigated system," Steduto said.

Productivity Gap

Often a single or just a few solutions to address water productivity are described. In reality, the relationship between yield and water consumption is much more articulated, Steduto said. If a crop is improperly managed, perhaps due to poor fertility or disease, productivity decreases while water consumption remains the same. Similarly, if an improved genetic variety is introduced, productivity may increase using the same amount of water. However, additional options exist. For example, transferring nonproductive evaporation to productive transpiration increases yields while using the same amount of water. This transfer can be achieved by mulching, increasing plant density or using a plant variety that grows earlier in the season, thereby covering the ground sooner. In yet another option, a crop may have deeper roots that take up a larger soil volume. In that case, water productivity remains the same. To produce more, the plant must consume more.

"You can see that there are several situations, several results, depending on the condition," Steduto said. These conditions can be the climatic environment, such as seasonal shift, evapotranspiration control or carbon dioxide enrichment; or genetic approaches, such as changes in productivity, phenology, canopy or root growth rates and resistance. Conditions also can stem from agronomic practices, such as managing soil health and fertility, pests and diseases, and weed control.

"You need to have a comprehensive view of what is happening in the field in order to make sure that you are increasing the fertility, the productivity of your crop," Steduto said. Actions taken to improve productivity may counteract each other and fail to produce the intended results. For example, wheat and barley yields improved tremendously after the 1960s Green Revolution during normal rainfall conditions. However, under drought conditions, the same varieties produce less than traditional varieties.

In addition, average estimated pre-harvest yield losses can reach 40 percent, due to insects, weeds and pathogens. Agronomic practices that protect crops from these losses will be reflected in water productivity. "There is a degree of substitution for all of them, and you need to take all of them into account," Steduto said.

Water productivity increases as yields initially increase, but fewer gains are made as yields continue to improve. At that point, the irrigation system has been maximized. To increase water productivity, attention must be paid to filling the yield gaps at lower yield levels, he said.

Assessment Gap

The relationship between yield and water use varies dramatically in different macro regions worldwide, such as China's Loess Plateau, North America's Great Plains and the Mediterranean Basin. What makes some farmers more productive than others, with the same water consumption? Steduto asked. "We need to understand what are the causes of all this; otherwise, we cannot intervene."

Studies to answer this question have been done, but not systematically. A variety of causes are found in differences in land and water management, plant nutrition, diseases, varieties and technology. FAO would like to study these differences systematically and is using satellites to monitor maize, rice and wheat at the global level. By detecting final yield and water consumption through evapotranspiration, the organization hopes to assess the variability of water productivity worldwide to intervene more effectively.

Systematic assessment scans help analyze causes of variability. For example, wheat yields are much higher on the Indian side of Punjab than on the Pakistani side. The difference in agricultural intensity is clearly visible at the Indian-Pakistani border, though they share a similar agro-climatological zone. India's more advanced irrigation infrastructure allows for more efficient and uniform water distribution, Steduto said.

Analyzing differences between irrigated and rainfed conditions also provides useful insights. In Morocco, for example, analyzing water productivity and frequency between irrigated and rainfed areas shows that irrigation increases water productivity, but much overlap exists between the two systems. This observation helps explain why certain rainfed systems have greater water productivity than irrigated systems. The variability can be explained by the location of each system and differences in soil type and climatic conditions.

Water productivity at the global level also can be scored. For example, Egypt is one of the most water-productive wheat growers in the world, as are Chile and Mexico. In contrast, Turkmenistan and Iran have low water productivity when growing wheat.

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Cost-benefit Gap

Prior to the 1960s, U.S. maize productivity had plateaued. Then, yields began increasing dramatically with improved varieties, irrigation, fertility, crop production and other advances. The same is true for China and Latin America, though not reaching U.S. productivity levels. Sub-Saharan Africa, however, has not changed since the 1800s or even the days of the Roman Empire, Steduto said.

A skilled American farmer dropped into the conditions faced by a Sub-Saharan African smallholder probably would not fare any better, primarily due to the high cost of adopting technology, he said. The inputs are so difficult to obtain that African farmers cannot do as well as farmers with greater resources. Market access also is a big problem in Sub-Saharan Africa. Remote locations, dirt roads impassable in the rainy reason, and high transport and transaction costs limit market access. In addition, farmers face droughts, floods and price risks. Market price distortions occur because middlemen often determine prices that keep producer incomes low, but consumer prices high.

"You have to be organized," Steduto said. "You have to increase the negotiation skills. You have to organize your added-value chain in order to reach the market." Because growing urbanization is expected, the importance of the value chain will continue to increase. Under these conditions, improving African farmers' situations is difficult.

FAO is benchmarking crop productivity for land and water, using basic statistical programs and modeling at the country level. The organization also uses remote sensing assessments and socio-economic analyses to identify the limiting factors for filling the cost-benefit gap to reach water and land productivity potentials.

Conclusion

Without a comprehensive view of crop productivity that includes water and land, agronomy, technology, the market, economy and other factors, the risk of failing to raise water productivity is high.

"The path to the solution … requires also filling the gap from knowledge to implementation," Steduto said. Research and education cannot be disconnected from implementation. Without strategic partnerships that encourage the flow of knowledge, it may sit on the shelves instead of being applied in the field.

"Agriculture needs to be more productive and more resilient … and also has to be more accountable in social, economic and environmental terms, which means it also has to become more and more high-knowledge content, high-tech content, high precision," he said.

Assessing land and water productivities, especially productivity variability, illuminates the causes of low productivity and is a strong basis for implementing effective policies and intervention strategies. This knowledge also will provide better understanding of what is manageable to better prioritize policy measures and implementation strategies.

Global Changes and Their Impacts on Water and Food Security: The Challenge of the Century?

András Szöllösi-Nagy
Rector, UNESCO-IHE Institute for Water Education, the Netherlands

András Szöllösi-Nagy discussed the effect climate change has on the hydrological cycle, the risks to humanity and the solutions needed to adapt to a hydrological transformation.

"Water will have a principal role in food security in the coming decades," Szöllösi-Nagy said. That role is becoming more complicated. Global politics have long determined global and local agricultural market behaviors, but a strange phenomenon has recently developed in which local market behavior has a global impact. For example, when a Tunisian vendor became so enraged by his interaction with a corrupt policewoman that he committed suicide, it started a chain reaction that led to major political change in the Middle East. "The interconnection between politics, water and prices is very, very close," he said.


András Szöllösi-Nagy

Hydrological Acceleration

The dramatic increase in natural disasters over the past 50 years suggests the Earth's hydrological cycle may be changing. If so, the amount of water will remain the same, but extreme events will likely intensify, which would increase human risk and vulnerability to floods and other natural disasters.

Increasing water hazards also would greatly challenge food production. Flood losses already have significantly affected countries' gross domestic products, particularly in a belt that spans Western Europe to Southeast Asia. Pakistan's flood in August 2010 caused $40 billion in damage and has knocked out the country's economy for the next several years. Big cities also are experiencing the new phenomenon of subsurface flooding.

"Subjectively, it feels that something is fishy with the hydrological cycle," Szöllösi-Nagy said. "But can we prove that?" Studies show less water is available to people. In 1975, more than 30,000 cubic meters per person per year were available; today just 5,000 cubic meters are available. The hydrological system is a renewable cycle so the world won't necessarily run out of water in 25 years, but it is an important signal, he said.

Although the hydrologic cycle is renewable, it is finite. Of the world's total water resources, just 2.5 percent is freshwater. Of that 2.5 percent, 80 percent is glacial or permafrost. Of what remains, 90 percent is found in aquifers and groundwater

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> *"Subjectively, it feels that something is fishy with the hydrological cycle. But can we prove that?"*

reservoirs. Therefore, what is available to humans represents just 0.007 percent of total water, the so-called James Bond phenomenon.

Some believe a crisis is looming and that water resource policies and practices must change. As evidence, Szöllösi-Nagy noted that in the 20th century the global population increased threefold, while water withdrawal increased sixfold. In addition, 80 percent of diseases are waterborne or water related, and access to improved sanitation, a U.N. Millennium Development Goal, is getting worse, not better. That African sanitation is 72 years behind the Millennium Development Goal is unacceptable, Szöllösi-Nagy said.

"We have been playing with the hydrologic cycle over the past 300 years and very notably ever since the Industrial Revolution," Szöllösi-Nagy said. "However, we never understood clearly: What is the impact of tampering with the cycle?"

Several drivers are changing the cycle's behavior, from technological advances to climate change. But the most important driver is population growth, he said. In 40 years, the world population will reach 9 billion people. The two other biggest drivers are poverty and pollution. Forest clearings increase runoff and flooding, and pollution from chemical compounds and pesticides affects water quality as water heads seaward, causing 80 percent of coastal pollution.

These global change drivers result in a series of global responses that appear to be exponential in nature: exponential increases in carbon dioxide release since the Industrial Revolution, in anthropogenic nitrogen fixation, in nitrogen flux to coastal zones, in species extinctions and in tropical rainforest losses. A linear increase in temperature also has occurred since global climate observations began 150 years ago.

If climate change accelerates rapidly, as some predict, and average temperatures increase between 2.5 degrees and 6.5 degrees Celsius, the hydrological cycle will greatly accelerate. As greenhouse gases trap heat in the atmosphere, evaporation and transpiration increase, which, in turn, increases the probability of cloud formation. Cloud cover increases the likelihood of rainfall, and therefore flooding.

Polluted canal in Delhi

Flooding in China

But is the hydrological cycle accelerating? is a question many scientists have asked. If the climate is changing, then the hydrological cycle must be accelerating, Szöllösi-Nagy said, but proof does not yet exist. Global hydrological data show runoff is decreasing in some watersheds but increasing in others. Yet the greater frequency of floods seems to indicate that something is wrong with the hydrological cycle, he said.

Major floods, so-called 200-year floods, are happening multiple years in a row. "All our tools, which are based on the assumption of stationarity, are not relevant anymore. … We have to go back to our design tables and then design a completely new toolkit that's capable to deal with the non-stationarity of the processes, including climate change and climate variability," Szöllösi-Nagy said.

Though signs of climate change are everywhere, uncertainty remains. Over the past 30 years, glaciers have clearly retreated. But last year the process seemed to reverse, and glaciers are again advancing. In the face of uncertainty, the precautionary principal should be applied, and humanity must develop methods to adapt to these changes.

Increasing buffering capacity is one option that must receive more attention, Szöllösi-Nagy said. Reservoirs are a buffer against hydrological variability. However, opposition to storage and hydropower has influenced policies for the past 20 years. "But let's be clear," he said. "There is no other option but to increase the buffer capacity to deal with the uncertainties."

Buffering capacity is unevenly distributed globally, from a North American high of 6,000 cubic meters

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per person of water storage to Ethiopia's 43 cubic meters per person. Countries with small buffering capacities must be able to deal with hydrological variability.

The biggest adaptation potential lies with groundwater resources. Ninety percent of unfrozen water is underground, capable of providing water for meeting agricultural and other water demands well into the future. Yet groundwater is an extremely vulnerable resource and must be handled carefully.

Making Decisions

The major problem caused by climate change will come not from a 2.5-degree temperature rise, but from water, whether due to rising sea levels or an increased prevalence of flooding due to hydrological cycle acceleration.

Water is the common element in many of the world's systems, connecting nature, society, culture and religion, and is the common thread throughout the Millennium Development Goals. Water, however, does not necessarily connect to politics. The message that a water crisis is looming has not reached the political community, and raising the profile of water nationally and internationally poses a big challenge, Szöllösi-Nagy said.

Decision-making and policymaking must be based on good data. For the past 30 years, technology has advanced tremendously. Computational barriers to simulate processes no longer exist, but information must reach decision-makers. Hydroinformatics, a new tool, integrates data, models and humans by synthesizing monitoring information, using the data to create models and disseminating results to decision-makers.

Glacial melting in the Antarctic

Szöllösi-Nagy is optimistic that the technology is available to deal with the water crisis, and the machinery already exists to observe the hydrological cycle, from which forecasts can be made. Yet the capacity to monitor the water situation remains limited because hydrological observations are unevenly distributed globally. Most observation stations are located in North America, Western Europe, Japan and New Zealand. Germany alone gathers more hydrological data than the African continent. Because climate change models are calibrated against data coming from these limited regions, assumptions – and policies – are made using biased data and models. "Data and data limitation is a major source of risk and vulnerability," Szöllösi-Nagy said.

Conclusion

Water will become an increasing source of conflict. Nearly 40 percent of humanity lives in watersheds or aquifers shared by more than two nations, and conflicts will affect agricultural water management. However, several examples show that water can be a source of cooperation, such as the Jordan River Basin, and such cooperative arrangements should be encouraged.

Szöllösi-Nagy said he believes enough water will exist in the century ahead, including water for agricultural production. "But we have to generate the political will to do things right, the capacity to do it right and the resources to do it right now," he said. The challenge is to more effectively transfer scientific findings to practical technologies and to improve economic situations and institutions in the least developed and emerging countries.

The biggest challenge, however, is getting politicians and the general public to think about water.

Irrigated field in South Africa's Limpopo Basin

The solution lies in water education and capacity building. Partnerships, such as the cooperative agreement between the Robert B. Daugherty Water for Food Institute and UNESCO-IHE, and investments in education are critical to finding solutions, he said.

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Industry Leaders Panel – Challenges and Potential Solutions

Mogens Bay
Chairman and CEO, Valmont Industries Inc.

Carl Hausmann
Managing Director, Global Government and Corporate Affairs, Bunge Ltd.

Kerry Preete
Senior Vice President of Global Strategy, Monsanto Co.

John Briscoe, Moderator
Gordon McKay Professor of the Practice of Environmental Engineering, Harvard University

Technology is advancing rapidly and the three panelists – representing an irrigation equipment manufacturer, a biotechnology company and a global trading firm – agreed that with available or emerging technology, the challenge of increasing agricultural production for a growing population can be met, particularly as collaborations between private companies grow. But the public institutions necessary to provide infrastructure, regulatory systems and market access lag behind, especially in developing countries. Should private companies undertake the task of helping the public sector improve its capacity to boost global agricultural production?

When moderator John Briscoe of Harvard University asked that question of the audience, an overwhelming 95 percent of respondents said they believe private companies should help. The panelists agreed: public-private partnerships that not only meet technological requirements but also overcome institutional barriers to expanding global production will help countries meet the water for food challenges ahead.

"The perception is we have quite a bit on the technology side – but how can we walk on two legs?" Briscoe said. "How can we get the institutional framework and the technologies working together more effectively?"

Advancing Technology

The evolution of center pivot irrigation systems provides one example of technology's rapid progress, said Mogens Bay of Valmont Industries. Initially designed to apply water uniformly, pivots frequently overwatered in areas. Gradually, pivot irrigation became more water efficient, but even greater efficiency is needed.

"Technology now allows us to segment a field into more than 5,000 individual zones, which means you're now able to spoon-feed water exactly where it is needed depending on crop conditions, soil conditions, et cetera," Bay said. But such advances require more exact inputs, such as soil type or weather conditions. Applying precise data to center pivot irrigation is an example of the advances made possible by various industries sharing knowledge.

Carl Hausmann, Kerry Preete, Mogens Bay and John Briscoe

Asked how advanced technologies could be delivered to poor farmers in developing countries, Bay said that initially they can't. Wealthier, large-scale farmers who can afford the technologies will be the first adopters. Like other technologies, the price of new irrigation equipment will drop as it becomes more popular.

Briscoe also provided a model from Brazil in which small-scale farmers unable to take advantage of technological changes in irrigation systems form connections with larger farms. "You get them, in a sense, all pulling together," he said. "I think it's the sort of model which gets to the ability of bringing poor people into systems that are much more knowledge intensive."

Public-Private Partnerships

"There's a great deal that we can do when we get our technologies, our infrastructure – the private sector and the public sector – working together," Briscoe said. He cited three examples of successes across the development spectrum.

In the Bangladeshi interior, poverty has lessened and a woman's average life expectancy has risen from 46 years in the 1970s to 68 years in 2000, thanks in large part to the government's effort to protect land from flooding and to make irrigation possible.

Brazil, in defiance of the prevailing global view to cut agricultural research funding, instead continued financing its researchers. Today, Brazil produces four times more than it did 30 years ago and outperforms countries that slashed agricultural research funding. Ninety percent of Brazil's growth came from total factor productivity, or knowledge growth, and not from increases in land, labor or capital.

Briscoe's final example was Australia, whose new water policies created a water trade system, encouraged technology adoption and gave institutions tremendous flexibility. These reforms enabled Australia to weather an eight-year drought. With just 30 percent of the water available eight years ago, the Murray-Darling

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Basin – Australia's irrigated heartland – maintained the same level of agricultural output.

Bay said he agreed that government policies significantly impact agricultural production. "A farmer doesn't live in a vacuum," he said. "If government does not deliver the infrastructure necessary for a farmer to be successful – whether it is roads, electricity or water – there's no way you're going to get agriculture productive in that part of the world."

Mogens Bay

To boost development, public entities have become more willing to reach out to private companies, Briscoe said. In Punjab, Pakistan, officials have decided the state could increase production three or four times using available land and farmers, but outdated physical and regulatory infrastructures handicap agricultural growth. The state has asked the private sector to help modernize its public systems. The process is delicate, Briscoe said. "If you get private companies in, are they doing it for their own good?" But it's an exciting area of development, he said, and one the World Bank is encouraging in other countries as well.

Kerry Preete of Monsanto Co. explained how the company engages with governments through organizations such as Water Efficient Maize for Africa (WEMA), a collaboration of private companies, research institutes, nongovernmental organizations and governments trying to improve African smallholders' yields through improved maize hybrids and technology. African nations, in particular, have been reluctant to adopt genetically modified organisms (GMOs), and these partnerships help educate governments about their benefits.

Preete cited Burkina Faso's introduction of Monsanto's bioengineered Bt cotton as a successful example of Monsanto's efforts to educate governments. "We think the more that governments can be involved in bringing this technology into the marketplace, to understand it, that's a good model for us to pursue," he said.

While panelists expressed confidence in biotechnology companies' ability to ensure product safety, they agreed that strong regulatory systems also are necessary. Briscoe said, "My sense is that this process will only work well when the public has confidence in a public institution doing the monitoring, as it does in the United States and these countries." Without that confidence, questions regarding safety will remain, and private services and products, such as GMOs, will have trouble entering the marketplace. Assisting in establishing independent monitoring systems might be one way in which private companies can help governments build capacity, he suggested.

Preete said Monsanto favors a strong regulatory environment, guided by a common set of regulations developed globally and run by government institutions. "When there is no

regulatory system, the products don't get there," he said, and as result, farmers have fewer choices. A global set of regulations also would assist governments unable to develop their own.

Carl Hausmann of Bunge Ltd. said that in addition to regulations, judicial remedies also could safeguard the process of introducing GMOs because threats of lawsuits push big companies to a high level of attention to food safety. "I think both judicial treatments of mistakes as well as regulatory regimes are at the heart of this," he said.

From the audience, Jeff Raikes of the Bill & Melinda Gates Foundation described the role of philanthropy in strengthening developing countries' regulatory capacities. The Gates Foundation is investing in African regulatory systems to put structures in place that allow better inputs to enter the marketplace.

Bay said he agreed that philanthropy will play an even bigger role in the future. "I think we have plenty of examples of philanthropy standing in where government is not doing as good a job as they should." Research, for which the availability of public funding is decreasing, is an example of an area to which philanthropy can contribute, he said.

Difficult Decisions

Hausmann said he believes it's possible to meet the global food demand projected for 2050, but factors such as land and water availability, preservation of biodiversity and labor issues must be carefully considered. "How sensitive we are in meeting this demand going forward is really the critical thing we all need to think about."

Agricultural production must move to where crops can be produced most efficiently and where land and water are available, he said, which will require significant infrastructure and difficult choices. He cited Saudi Arabia and Morocco, which have discontinued wheat production because "crop per drop is not quite good enough. How do we get maximum value of the water we use?"

When asked about individual countries' food security if food production moves elsewhere, Hausmann responded that international trade never will account for a country's entire food source. Globally, just 12 percent of grains are internationally traded, and he believes doubling production will raise this to only 20 percent.

Hausmann also cautioned about the boundaries of public-private relationships. He said Zimbabwe, for example, should be allowed to decide whether it will permit GMOs. "Societies need to be governed locally, not by the private sector."

He said Bunge is participating in the global dialogue about agriculture by stating its values without dominating the conversation. "But neither do we want to have other people say, 'I have the dominant voice, and I will tell you what to do.'

"I think we will reach a better decision as a society if we get all the actors in the value chain working together, not only on the technical questions but on the societal questions."

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Agricultural Producers Panel – A View From the Field

James Cartwright
Director, Vegpro Kenya Ltd.

Jon Holzfaster
Ag Producer, Nebraska

Craig Kirchhoff
Owner, KFI West, California

Jim Pillen
Founder and President, Progressive Swine Technologies, Nebraska

Louis Sartor
Producer/Owner, Sartor Management Pty Ltd., Australia

Ronnie D. Green, Moderator
Harlan Vice Chancellor for the Institute of Agriculture and Natural Resources, UNL;
University of Nebraska Vice President

The panelists came from different corners of the world and a wide range of farms, but each described how he has markedly increased production using fewer resources, particularly water, largely because of advances in irrigation technology. Each also brought his unique perspective and insights acquired from farming under diverse agricultural and political circumstances.

Kenya

Begun modestly in 1979, Vegpro Kenya Ltd. today farms more than 6,000 acres of vegetables and 250 acres of greenhouse roses, producing about 250 tons of crops per week. The produce is trucked to Nairobi where Vegpro packs and labels it for sale, and it is flown or shipped daily to European markets. The company is the market-leading producer in Kenya where horticulture and floriculture are the top foreign exchange earners, said James Cartwright, Vegpro's director.

The company's wide variety of crops necessitates multiple irrigation methods, including center pivot, drip, fixed overhead systems, a drag system and misting. The company also grows hydroponic vegetables, re-circulating the water. Irrigation water comes from a lake, river and boreholes, but the company also invests heavily in rainwater storage.

The ease of center pivots contributed to over-watering, Cartwright said, so the company began

Craig Kirchhoff, Jim Pillen, Louis Sartor, James Cartwright and Jon Holzfaster

using a probe to monitor soils for water content. "I also keep reminding our managers that the best agronomy tool is a shovel." Water management changes resulted in 21 percent water savings in vegetable production and 11 percent savings in roses – and in healthier plants. Vegpro now uses 450 liters per kilogram of crops produced.

The company employs more than 7,000 people. In Africa, that translates to economically supporting about 60,000 people, Cartwright said. It also works with 3,500 small-scale farmers, who are better able to grow certain types of crops, such as peas. In Ghana, where the company is developing a 1,000-hectare project to grow crops that can't be grown in Kenya, it works with farmers through the Millennium Challenge Corporation. Vegpro provides farmers with seeds, training and a guaranteed market.

Cartwright said the company is proud of the benefits it offers workers, providing what the Kenyan government fails to, such as primary health care, pension plans and loans. The company's biggest challenges are inadequate regulations that allow over-extraction of water, farming in ecologically sensitive areas and risks from food safety issues.

Australia

Louis Sartor's 45-acre family-owned citrus farm sits within the Murrumbidgee Irrigation District of the Murray-Darling Basin, where 40 percent of Australia's farms and 75 percent of its irrigated

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> *"They've actually made us smarter farmers because we make decisions on what we grow according to the value of water."*

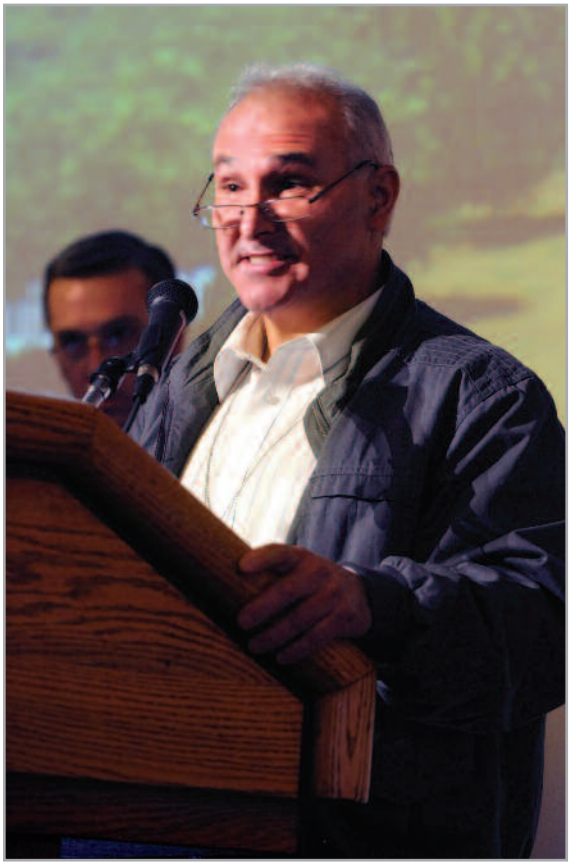
agriculture are located. Most farms are still family owned. About half of the Sartor farm's produce is exported to Asia and the U.S., and half is consumed through the local juice market.

After Sartor's father arrived from Italy in 1956, he grew a variety of fruits using traditional furrow irrigation, bringing water from the Murrumbidgee River through a series of canals and on-farm concrete channels. In the 1980s, the family added pipe-and-riser water delivery systems. Better control of water flows saved about 2 megaliters of water per hectare, but trees received either too much or too little water, and their health suffered.

In the early 2000s, the Sartors converted to drip irrigation, saving another 3 million liters per hectare and doubling production from 3 tons to 6 tons per megaliter of water used. Drip irrigation and a soil monitoring system have allowed more precise monitoring of water movement, which reduces groundwater intrusion and herbicide use while improving fertilizer uptake. These changes allowed the farm to increase plant density from 240 trees per hectare to 1,000 trees. That and other management changes significantly increased production. The Sartors recouped their drip irrigation investment within seven years.

"Even though our enterprise is only small, we still survive because of technology," Sartor said. "We marry the plants' needs exactly to the water that we have."

The water-saving technology helped the farm weather Australia's worst drought in more than a century. Australian farmers can earn additional income from their water savings through a national water trade system. During the drought of the mid-2000s, the Sartors sold water, taking advantage of the Murrumbidgee River's ability to sustain the area's horticulture during the drought. Then they bought water back as a buffer against future droughts.



Louis Sartor

Treating water as a commodity gives farmers an incentive to adopt management practices that save water, Sartor said, adding that farmers may decide to not grow crops if the water is valued higher elsewhere, as during the drought.

"It's a marketplace tool that they use," he said. "And they've actually made us smarter farmers because we make decisions on what we grow according to the value of water."

"We'd had maybe 10 or 15 years of debate on water with emotion, and we got nowhere. … So take the emotion out of water – trade it as a commodity."


Ronnie D. Green

Nebraska

Jon Holzfaster, owner of Holzfaster Farms, and Jim Pillen, president of Progressive Swine Technologies (PST), grew up on Nebraska farms that adopted center pivot irrigation. Each described the yield and water-saving benefits of those early irrigation systems and of subsequent technological advances.

The son of an early center pivot irrigation dealer, Holzfaster has seen irrigation evolve over the years from high-pressure, water-intensive units to water- and energy-efficient models. New models operate more efficiently because of changes like dropping sprinklers closer to the crop canopy to reduce evaporation. His family's farm, near the confluence of the South Platte and North Platte rivers in southwestern Nebraska, irrigates with groundwater from the High Plains Aquifer and uses digital moisture sensors and Internet-based management systems for greater watering precision.

Evolving tillage practices also have translated into tremendous water savings and erosion control, Holzfaster said. Strip tilling, in which only a narrow seedbed is tilled, leaves nearly the entire previous season's crop residue on the surface to act as a groundcover, reducing evaporation loss.

"We try and do whatever it takes to operate as efficiently as possible," he said. The farm grows corn, soybeans, popcorn, edible beans, wheat and alfalfa and operates a cattle finishing operation.

Pillen, who grew up on a small farm in central Nebraska, described similar advances to center pivot irrigation that have increased corn yields from 50 bushels per acre in the 1960s to 220 bushels per acre today. Corn and soybean production is part of PST's cycle that raises 1.25 million pigs annually. The number of bushels of corn required to produce an average-sized pig 40 years ago now produces hogs on the upper end of the normal range, he said.

The key to PST's efficiency, Pillen said, comes from harvesting the manure to put back on the crops as fertilizer, providing a competitive advantage of $200 per acre. The cycle also conserves water, he said. "Every drop of water we take up goes

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through a pig, and we put it back on our cropland to grow more crops. … It's totally contained."

Some of the fertilizer is delivered via center pivots after being collected in an anaerobic lagoon. The rest is collected as slurry and injected into the ground using drag-hose injection.

About 22 percent of U.S. pigs are exported, Pillen said. "We have to be a global competitor. Our focus is to be a least-cost producer, providing a value-added product."

California

Craig Kirchhoff grew up on a corn and soybean farm in Nebraska's Republican River Valley and tells a similar tale of his father's early adoption of center pivot irrigation and the subsequent increase in yields and water savings. In the 1980s, he took his farming expertise to northern California, where he converted more than 1,100 acres of wine grapes from flood to drip irrigation for Bogle Vineyards. Eight years ago, Kirchhoff started his own vineyard, KFI West, in the Clarksburg Wine District in the northern section of the Sacramento River Delta. He grows chardonnay grapes on 35 acres of flood-irrigated land and on another 65 acres using drip irrigation.

Wine grapes are sensitive to overwatering, and because wine depends on high-quality grapes, precise timing and amount of water are critical. "Drip irrigation gives me so much flexibility in the vineyards," he said. "It's a comfort to be able to walk out and push a button and know that every vine in that vineyard in five minutes is getting water, if that's what it needs." He also attains about 50 to 70 percent water savings.

To understand his plants' needs, Kirchhoff uses soil sampling, petiole sampling and pressure bombs, in which pressure is pumped into the leaf. The more pressure required for the leaf to release water, the drier the plant. He also uses a cover crop that helps dry the vineyards and reduces weeds but goes dormant in the summer so it doesn't compete for nutrients.

Kirchhoff said his perspective from farming Nebraska corn and California grapes helps him appreciate the benefits in productivity and water savings different types of irrigation bring to both.

A vineyard that uses drip irrigation

James Cartwright

Conclusion

The panelists agreed that the technology is available or will be soon to meet 2050 targets for feeding the world, but meeting that goal will require continued effort and a vision for the future.

Kirchhoff believes the problem isn't lack of technology, but educating users. "Education is key," he said. "You have to be able to have a workforce that uses that technology and to keep those people up to speed."

Another key component is government regulation, Cartwright said. In Kenya, for example, a non-punitive environment that encourages small-scale farmers to use water more efficiently is needed to ensure water is available for others to grow more food.

He also urged development projects not to ignore commercial farmers. "Development, I believe very, very strongly, that is completely focused on the small-scale farmer and on pro-poor development will fail," he said. "It's failed for 40 years."

Wage incomes on commercial farms bring economic stability to families and communities and should be encouraged, Cartwright said.

When challenged about the role of small-scale farmers, Cartwright said he agreed that a mix of commercial farming and small-scale farming is necessary. But, he said, "in every area in the world, countries that are developing, develop on the basis of economies of scale in agriculture, and Africa will not be any different."

From the audience, John Briscoe of Harvard University said that agriculture is widely regarded as a primitive, environmentally destructive activity unworthy of support. To be successful moving forward, he said, the Robert B. Daugherty Water for Food Institute must communicate the importance of the challenges ahead and establish a vision around which people can mobilize.

Working cattle in Nebraska's Sandhills

Paths to Solutions

Securing Water for Agriculture: California's High-Stakes Challenge

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Senior Vice President of External Relations; Vice President, Division of Agriculture and Natural Resources, University of California

Roger Patterson
Assistant General Manager, Strategic Water Initiatives, Metropolitan Water District of Southern California

Jason Peltier
Chief Deputy General Manager, Westlands Water District, California

Steve Thompson
U.S. Fish and Wildlife Service (retired)

Ann Bleed, Moderator
Adjunct Professor, School of Natural Resources, University of Nebraska–Lincoln

The Sacramento-San Joaquin River Delta, home to an extraordinary biodiversity of wildlife, also provides two-thirds of Californians and most of the state's farmland with freshwater. Today, the ecosystem and the water supply are at risk as urban populations grow, climate change affects rainfall and snowpack runoff, and fish populations collapse.

For decades, water users have battled over how to meet expanding urban and agricultural water requirements while preserving critical habitat, but a long-term solution has proved elusive. With $400 billion of California's economy dependent upon water that passes through the California Delta, the area remains an enormous economic and political driver.

"I think we're at a dysfunctional impasse at this point," said Steve Thompson, formerly of the U.S. Fish and Wildlife Service. "The infrastructure is old. … It's not designed well in the first place, but it's there. And the environmental laws that we celebrate sometimes as so important, just aren't working in California. We've come to gridlock."

Moderator Ann Bleed said California's struggle illustrates the problems many communities worldwide face as climate change and water demands escalate.

California Water

California annually receives 200 million acre-feet of water from precipitation and river flows, but only 40 percent is storable. Of that, urban districts

Steve Thompson, Daniel Dooley, Roger Patterson, Ann Bleed and Jason Peltier

use 11 percent, agriculture takes 41 percent and the rest is dedicated to environmental purposes. Two-thirds of California's freshwater supply originates in the north, while two-thirds of the demand comes from the south.

The "switchyard" in California's water system is the Delta, an estuary formed by salt water entering through San Francisco Bay and freshwater primarily from the Sacramento and San Joaquin rivers. The state sends water stored in northern California south down the Sacramento River. After passing through the Delta, freshwater is delivered to water districts as far south as San Diego via canals, pipelines and pumps. To maintain the freshwater supply, the state sends enough freshwater into the Delta to hold back tidal currents.

The Delta also has become an important agricultural area. Starting in the 1860s, farmers built unengineered levees to create islands of farmland by draining once-vast tule marshes that were critical parts of the Pacific migratory flyway. Over the years, however, the peat soil has oxidized, causing land to subside below sea level. Occasional levee failures and subsequent flooding pose ongoing risks.

Thompson said, "In a relatively short time, we've drastically changed the state of California from a biological perspective." Several fish species have collapsed, most notably the Delta smelt. While some blame the state's water delivery system, others point to additional causes such as industrial pollutants and large numbers of non-native fish species. In the late 1960s, conflicts developed as new federal regulations began challenging water allocations and projects' environmental impacts. By the mid-1980s, the federal government had gone from being a major agricultural promoter to a regulator, Thompson said.

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And by the 1990s, new laws requiring states to protect species and their habitats put Delta conservation in competition with farms' and cities' water needs.

Other risks loom. The sea level measured in San Francisco Bay has risen 6.5 inches in the past century and is predicted to rise another 6.5 inches to 55 inches in the next century. Scientists also give the area a two-thirds probability of experiencing a significant earthquake by 2030, which would dissolve the levees, causing flooding and saltwater intrusion. If that happens, freshwater would no longer be able to move through the Delta for several years, devastating California's economy.

Seeking Solutions

The panelists agreed that California's goal is to meet human water needs while protecting the environment, but each highlighted the unique concerns of the group he represents.

After laws reallocated water from human uses to environmental conservation, farmers could no longer predict water supplies from year to year, creating tremendous economic disruption, said Jason Peltier of Westlands Water District, the state's largest agricultural district. To cope with variability, the Delta area experienced large crop shifts and made enormous investments in irrigation systems. However, Westlands purchased 100,000 acres of farmland and reclaimed them from irrigated agriculture.

"There's been a huge investment of management time into the whole water thing," Peltier said. "We also continue to overdraft our groundwater and this is regrettable. But when you're facing 40, 60, 90 percent reductions in your water supply … it's put people in a really complicated place."

Roger Patterson

His district seeks to regain consistent water allocations for agricultural use.

Roger Patterson of the Metropolitan Water District of Southern California, the largest urban water district, said southern California's population has grown by 4.5 million since 1990, but water allocations remain the same. About one-third of the district's water comes from the Delta, and though it has managed so far, Metropolitan also wants to recover a reliable water source.

Thompson said he worries that without a long-term solution, Californians will eventually abandon the goals of saving endangered species and conserving California habitat in general. "If it fails, it's something that wakes me up in the middle of the night," he said. "We're much better off to do conservation

ahead of time, over a 50-year period, than to face that war, from my perspective."

Peltier credited Thompson with encouraging federal, state and local government agencies in California to develop a comprehensive long-term habitat conservation plan, rather than tackle each risk or endangered species independently. "Single-species management almost never works," Thompson said. "You need to work on the whole habitat, and you have to have a long-term pattern."

About five years ago, participating agencies embarked on developing a plan that would protect the Delta's ecological health while providing more reliable water supplies. The resulting Bay Delta Conservation Plan proposes constructing water conveyances to bypass the Delta, either through channels or, more likely, a 40-mile subterranean tunnel, at an anticipated cost of $12 billion. The plan also calls for ecosystem restoration, such as increasing intertidal habitat and addressing other stressors, such as waste discharge plants. The plan, recently proposed, is under review.

Scientific Uncertainty

Peltier said, "The one factor that horribly complicates our discussions in the Delta is the disagreement over the science and what science tells us." The government and water users spend $15 million to $30 million annually researching the Delta ecosystem, but Patterson and Peltier said they believe scientists are too entrenched in defending their positions. "They're not bringing us solutions in any form," Peltier said. "They're bringing us problems and not helping us figure out how to fix the problems."

University of California's Daniel Dooley agreed that university engagement in public policy issues has been episodic and faculty driven, but UC is working on providing more structured engagement across disciplines and engaging stakeholder communities.

Peltier and Dooley said the issues are too complex and open to interpretation for science to provide unequivocal answers. However, they disagreed on how to proceed in the face of scientific uncertainty. Avoiding action while waiting for the perfect answer has precipitated the crisis, Dooley said. "You need to do the best you can based on the data we have … and make sure you have a process that allows you to adjust as you learn more and proceed, and we've been unwilling to do that." Instead, he said, imposing rigid structures has made it difficult to adapt.

Peltier said an adaptive process isn't feasible. "It sounds great on paper," he said. "My great concern with saying 'adaptive management is going to save the day' is that it inherently is risk taking." Making a potentially wrong decision with the idea that it can be changed later is impractical, he said.

Jason Peltier (center)

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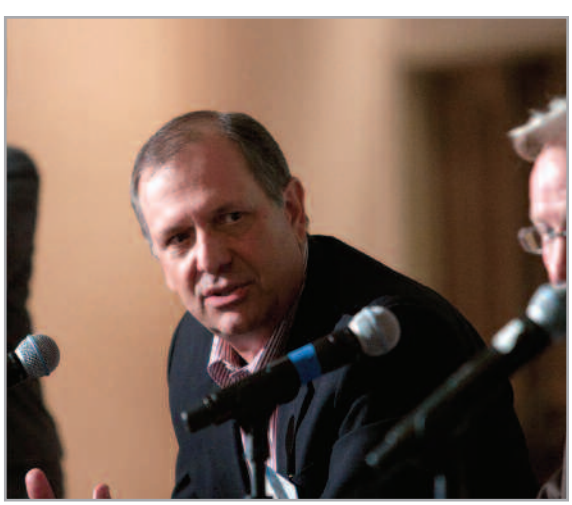
Dooley countered that risk is always present; the question is whether the risk is greater or less than doing nothing. Adaptive management establishes parameters to provide safeguards that soften risks, such as caps on how much additional water can be applied, and when and how the issue can be re-examined.

Thompson said plenty of data exist, but a structured decision-making process is lacking, impeding the ability to understand risks and make strategic decisions based on risk analysis. "Unfortunately, right now, we don't have the ability yet to sort of take those risks, to do adaptive management, do it up front. … I think we need to figure out ways we can take those risks together."

Building Trust

Several panelists agreed that strong government leadership is missing. Thompson said participant leadership also is lacking. "We need really good, strong leadership in landowners and farmers and counties and everybody else it takes to step up and do the right thing on the ground and make sure they're doing a good job for conservation, but a good job for the landowner also," he said.



Daniel Dooley

He cited several cases in which compromises between conservation and agriculture resolved similar conflicts. In the early 2000s, disputes arose on the Klamath River that flows through southern Oregon and northern California. Both states, four American Indian tribes, farmers and federal wildlife agencies initially fought over competing water demands and protecting endangered salmon. After two years building trust, however, they eventually reached an agreement.

Thompson said trust also played a role in resolving issues with California and Nevada's Truckee River, one of few western rivers where water is stored for wildlife and run by federal biologists. The arrangement initially worried farmers and urban water districts, but over 20 years it has earned respect from communities and is helping fish habitats recover. "We need to look for those types of flexibility," Thompson said. He elaborated that current environmental regulations lack flexibility, particularly when decisions are made through litigation.

Audience member Louis Sartor, a farmer, described a similar conflict in Australia's Murray-Darling Basin. To move forward, each group determined the minimum amount of water it needed and on what it could compromise. Eventually, fewer concessions were necessary and participants understood they shared similarities.

"Ultimately, unfortunately, [farmers are] the ones that are going to have to give," Sartor said. "There's got to be a compromise on the environment side because, you know, that's just the way it is." Farmers knew negotiations might result in a smaller irrigation area, but they also achieved more efficient water delivery and re-invested water savings into agriculture so the

The Delta is critical to agriculture and fragile ecosystems.

baseline didn't change much, he said. Farmers also were compensated for their water so they had less financial risk. Compromise was the key to Australia's success, which seems lacking in resolving the Delta conflict, Sartor said.

In response, Peltier said that 20 years ago, California's agriculture sector had too much water taken from it with nothing in return. "We're not really in a giving mood anymore," he said.

Dooley added that Australia benefits from a national water policy, something the U.S. lacks because most Americans historically have not had to worry about limited water resources.

Conclusion

Patterson said Californians remain largely unaware of the gravity of the Delta's problems. "If we get into this big political debate, people have to know, and they have to be talking to their electorates that we need to make the investments," he said. By emphasizing water conservation, the Metropolitan Water District hopes to raise awareness and reduce stress on the system. Efforts to encourage conservation have reduced water use 30 percent over the past four years, and Metropolitan seeks further savings. But how do you get that many people to care? Patterson asked. "The biggest way to get people to conserve is through their pocketbook, and I don't care whether you're a farmer or an urban person … in the end, money talks."

Paths to Solutions

Pathways to Greater Food Production: Lessons From Ethiopia

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Annie Cafer
Graduate Student, University of Nebraska–Lincoln

Assefa Kumsa
General Manager, Oromia Water Works Design and Supervision Enterprise, Ethiopia

Martha Mamo
Associate Professor of Agronomy and Horticulture, University of Nebraska–Lincoln

Regassa Namara
Senior Economist, International Water Management Institute, Ghana

Kindie Tesfaye
Dean, College of Agriculture and Environmental Sciences, Haramaya University, Ethiopia

Yitbarek Wolde-Hawariat
Vice President for Research and Community Services,
College of Agriculture, Wollo University, Ethiopia

Robert Yoder
Consultant, International Development Enterprises

Raymond Hames, Moderator
Professor and Chair, Department of Anthropology, University of Nebraska–Lincoln

Charles Wortmann, Moderator
Professor of Agronomy and Horticulture, University of Nebraska–Lincoln

Ethiopia continues to struggle with food security. For 30 years, agricultural productivity levels have remained flat at 1.6 tons of grain per hectare, and millions of Ethiopians continue to rely on food aid. Because agriculture represents nearly 60 percent of gross domestic product (GDP) and employs 86 percent of the population, stagnant productivity levels stifle Ethiopia's overall socioeconomic development.

The crux of the problem is Ethiopia's climate variability, several panelists said. Droughts occur each year, flooding is a problem in many regions and rainfall is often unpredictable. Because more than 96 percent of the country's agriculture is rainfed, annual rainfall patterns significantly affect productivity and GDP.

Panelists also said irrigation is key to increasing productivity, achieving food security and boosting Ethiopia's overall economic growth and stability. The government recognizes this and seeks to increase irrigated land area from 4 percent to 15.6 percent by 2015 using small-scale irrigation techniques and rainwater harvesting. The panelists described the enormous challenges the ambitious plan – and the country – face but also highlighted opportunities to overcome the obstacles.

"We have always had good plans and strategies," said Regassa Namara of the International Water Management Institute (IWMI). "Now the bottom line is implementation."

Irrigation's Potential

Ethiopia's water problem is becoming progressively dire as climate change brings more frequent extreme weather events. Heavy rainfall results in erosion, runoff, flooding, water pollution and drought, said Charles Wortmann of the University of Nebraska–Lincoln (UNL).

Charles Wortmann

Although Ethiopia's rainfed agriculture suffers from severe lack of rainfall at critical times, several panelists described the tremendous potential that may exist in surface water and groundwater supplies. About 122 billion cubic meters of water flow through Ethiopia's river basins annually, but mostly within a three-month period. More than 95 percent of this water travels to neighboring countries. Namara said, "I think Ethiopia's development lies in controlling these flows and making [water] available throughout the year for agriculture and also for all other sources."

Groundwater also represents a major potential water source. Assefa Kumsa of Oromia Water Works Design and Supervision Enterprise said many cite Ethiopia's 2.6 billion cubic meters of groundwater resources, "but this is based on very scanty knowledge." Researchers recently found evidence to suggest groundwater may be far more abundant. Kindie Tesfaye of Haramaya University said Ethiopia receives an average 848 millimeters of precipitation annually, an acceptable level if it can be stored.

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Assefa Kumsa

Kumsa said studies indicate that between surface water, groundwater and rainwater harvesting, Ethiopia's available water supply could irrigate more than 5.3 million hectares, 10 times more than current levels. Why then, Tesfaye asked, has Ethiopia failed to expand irrigated agriculture? In the past decade, irrigation has increased less than 2 percent and is used for only 4.3 percent of cultivated land.

Irrigation Challenges

Ethiopia hasn't invested in its water infrastructure and has limited water storage capacity. Panelists listed many things the country lacks to develop its water resources, including sustainable finances, accountability, manpower, market access, technological capacity and research.

Hydropolitics also play a role, Namara said. Political dynamics between Ethiopia and Sudan, for example, hinder efforts to dam the Blue Nile River. Additionally, Ethiopia's inherent lack of precipitation constrains adoption of new technology. "You cannot dictate farmers to adopt best seed variety or fertilizer when he is struggling with or gambling with the nature," he said.

Several panelists also noted Ethiopia's mixed agriculture sector of crops and livestock. Kumsa said the pastoralist and agro-pastoralist communities are most vulnerable to climate variability because droughts require people and their cattle to travel long distances for water. Armed conflict prevents others from traveling, increasing competition for local grazing land and water. Namara said water for livestock must be included in any models designed to increase water productivity.

To understand why Ethiopia has not taken advantage of its irrigation potential, one also must consider its human resources. Panelists agreed that Ethiopia lacks specialized labor, farmer training and professional development. Extension workers, in particular, lack the skills necessary to effectively do their jobs, several panelists noted.

Ethiopia's higher learning institutions have not provided the capacity building the country sorely needs, Tesfaye said. "The role of higher education institutions on agricultural water management has been very limited," he said. "Lack of organized research in agricultural water management in the country has contributed to the slow development and poor performance of irrigation agriculture in Ethiopia."

However, he said, higher education is poised to have a major impact on Ethiopia's future food security. Agriculture colleges, limited to just one until 1993, now number 14 and include programs in water management. Institutions should take advantage of factors that favor their continued

expansion, including the government's interest in infrastructure development and donors' renewed interest in agricultural investment due to increasing food prices and the subsequent rise in hunger.

Tesfaye said many challenges must be overcome, including a shortage of experienced faculty, inadequate infrastructure, high teaching loads that restrict research, limited international partnerships and brain drain. But he also said Ethiopia has ample opportunity to overcome these challenges and play a leading role in improving water management.

Irrigation Opportunities

Oromia Water Development Projects

Kumsa described three irrigation projects in the Oromia region that are improving living conditions. People in the Fentale and Tibila project areas are pastoralists and agro-pastoralists who rely on food aid due to frequent, severe droughts. Beginning in 2006, the regional government began building a series of canals to divert water from the Awash River to irrigate nearly 8,000 hectares, part of a 25,000-hectare irrigation plan. The land produces maize for the first time in 40 years, Kumsa said. When water first arrived, people grew crops to feed themselves. But after two or three harvests, they began growing high-value vegetables.

In Borana to the south, no surface water exists and droughts frequently cause severe livestock losses, he said. In 2007, the government found nearly 800 million cubic meters of groundwater annually, and a water transport system is currently under construction. Because people also will need grazing land, the project integrates rangeland development as well.

Unlike the lowland areas, the Central Highlands has adequate water resources. However, because tremendous population growth has made cultivated land a scarce resource, increasing land productivity through irrigation is needed. In 2009, regional and federal governments initiated pilot groundwater irrigation projects.

These projects have increased food self-sufficiency and demonstrated that change is possible, Kumsa said, noting that residents are already thinking about how to further transform their lives. But he stressed the need to quantify Ethiopia's water resources. Without that information, planning remains challenging and overuse is a possibility.

Regassa Namara

Other research is needed, including irrigation water management, water use efficiency techniques and agronomic improvements based on the area's climate and ecology. "We just delivered water; the people started (rotating) their crops. But which are the efficient crops? We don't know yet," Kumsa said.

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Drilling for Water and Income

Robert Yoder described International Development Enterprise's (IDE) pilot project that provides irrigation via hand drilling, while also creating small business opportunities. Hand drilling penetrates deeper into the water table than hand digging, allowing enough flow to support pumping, and thereby increasing the land area that can be irrigated, Yoder said.

IDE is training people to work as self-employed drillers. Charging about $2.50 a meter to cover laborers and equipment, drillers can earn an average net income of about $1,000, a significant increase above normal wage rates.

For farmers, an average 20-meter well and treadle pump costs $165 for drilling and pump installation. With that system, farmers can irrigate 1,200 square meters of vegetables, producing two crops a year in addition to rainfed maize and adding $840 in annual income. "This is the type of opportunity that IDE is trying to create for small farmers," Yoder said. "Gaining access to irrigation water is among the few opportunities the smallholders have to move from subsistence rainfed agriculture to something more sustainable."

Challenges remain, such as knowing where to drill, either because of lack of water or encountering hard rock. Yoder emphasized the need to map shallow groundwater resources in addition to the deeper aquifers Kumsa described. Initial capital costs for smallholders as well as capital investment for drillers and equipment manufacturers also remain significant obstacles. "How do you promote very low-cost technologies when there's very little capital in the field?" Yoder asked.

Microcredit and other types of loans are important but risky and need further development. "I'm convinced that the route of going to private sector investment in drilling provides an opportunity for rapidly scaling up," Yoder said.

Rainwater Harvesting

Rainwater harvesting represents another potential opportunity for irrigation, said Yitbarek Wolde-Hawariat of Wollo University. He described the benefits farmers who harvest rainwater have gained growing vegetables and increasing incomes. But, he said, while some areas receive sufficient rain, harvesting it remains limited. As with other types of irrigation, lack of credit keeps smallholders from adopting the technology.

Yitbarek Wolde-Hawariat

In other areas, water harvesting structures exist but rainfall is lacking. "If there is no rain, there is no water harvesting," Wolde-Hawariat said. Improving technology to collect rainfall does little good during droughts. Other challenges include poor awareness of the technology and its implementation, water shortages, lifting water to higher elevation and maintenance requirements. In lowland areas, storing water may increase malaria incidence.

Martha Mamo

Incorporating Social Sciences

Technology alone won't solve these complex issues, said Martha Mamo of UNL. Incorporating social science researchers to understand the challenges farmers and others face is critical to devising appropriate solutions. Mamo, UNL anthropologist Shimelis Beyene and UNL graduate student Annie Cafer described research conducted in collaboration with two Ethiopian universities that integrated physical and social sciences. Researchers gathered comprehensive baseline information from drought-prone areas to interpret the effects of future efforts to improve agricultural productivity and dietary practices.

Beyene said focus group discussions with farmers in two nearby areas demonstrate how differently water affects each community. In the lowland area, frequent droughts and saline groundwater limit harvests. As a result, farmers have relied on food aid for 25 years. In an adjacent highland district, farmers invested heavily in hand-dug wells to irrigate cash crops. The significant increase in incomes allowed farmers to diversify their operations in ways such as incorporating dairy breeds to sell milk. Now food secure, these farmers still struggle with fluctuating commodity prices and access to inputs and markets.

Cafer examined eight communities in highland and midland areas. In highland areas, farmers incorporate some form of conservation, such as terracing, tree planting or plowing. "They're all very aware of the consequences of their farming actions on the soil," Cafer said. "However, they do still experience a lot of crop loss even with the conservation and with irrigation." The midland communities rely on rainwater catchment for irrigation to grow cash crops. However, frequent droughts left them more vulnerable, and these communities were more reliant on food aid, she said. Few highland areas use irrigation so they experienced more crop loss; however, they had diversified their incomes enough to become more resilient to the economic impact of drought.

Conclusion

If Ethiopia is to achieve food security, it must build on its partnerships within the country and internationally.

Tesfaye said, "In the past we closed our doors, and we were boiling in our pot." Today, greater openness and a desire to work with others offer optimism for a different future. "There's no need to reinvent the wheel," he said. "There is a lot of experience; there is a lot of knowledge; there is a lot of technology out there."

Ethiopian universities, in particular, need not start from scratch. But they must establish and maintain effective national, regional and international partnerships to accelerate knowledge and technology development within the country, Tesfaye said.

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Scientific Sessions

3

Scientific Sessions

Quantitative Food Security: Yield Gaps, Water and Nitrogen Productivity

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Scientific Abstracts

Yield potential, water and N requirements of non-food biofuels

Sylvie M. Brouder, P. Woodson, L. Bowling, R. Turco and J. Volenec
Purdue University

Key words: water-use-efficiency, water productivity, N-use-efficiency, cellulosic biomass

Challenges abound in developing realistic estimates of U.S. yield potentials and water and nitrogen (N) requirements of non-food biofuels. For crops long cultivated for other purposes (e.g., switchgrass for forages), high-yield field trials may exist but still not accurately characterize performance relative to bioenergy objectives. However, existing field data may be sufficient to derive initial parameters for model-simulated potentials. For novel crops, field trials are only just being established across relevant U.S. agro-ecozones and data are too sparse to parameterize, calibrate and validate models. Additionally, the U.S. mandate to produce bioenergy crops on marginal lands complicates yield forecasts, as marginality is crop-specific. Precipitation and available soil water may be key yield drivers. Most candidate bioenergy crops are C4 plants and have comparatively high water use efficiency, with values of 237 and 400 kg H_2O/kg dry matter reported for *Miscanthus* and switchgrass, respectively. Based on the simple assumption that 60% of annual precipitation is available for crop growth, yield forecasts for the central U.S. are 22.4 and 13.3 Mg/ha for *Miscanthus* and switchgrass, respectively; these estimates closely match the few measured yields and suggest water availability will modify early, higher estimates of U.S. production potential.

Crop water productivity is closely linked to N status, but data on N-use efficiency for these crops are inadequate. Existing projections of bioenergy crop N requirements seem overly optimistic (e.g., 0-15 kg/ha/yr) since without a fundamental change in N physiology, N requirement scales with dry matter. Field data remains a critical limitation to forecasting.

Yield gap analysis: Implications for research and policies on food security

Kenneth G. (Ken) Cassman
University of Nebraska–Lincoln

Global carrying capacity for food production and our ability to protect carbon-rich and biodiverse natural ecosystems from conversion to cropland ultimately depend on achieving maximum possible yields on every hectare of currently used arable land. Yet for most major crop-producing regions of the world, including data-rich regions such as the U.S. Corn Belt and the Netherlands, there are no reliable data on actual yield potential. For irrigated systems, yield potential (Yp) is the yield obtained when crop growth is not limited by water, nutrients, or pests and diseases (Lobell et al., 2009; Evans, 1993; Van Ittersum and Rabbinge, 1997). For crops that rely on rainfall, water-limited yield potential (Yw) is the most relevant benchmark. Water resources to support rainfed and irrigated agriculture also are under pressure, making the efficiency with which water is converted to food – water productivity (WP) – another critical benchmark (Passioura, 2006; Grassini et al., 2011) of food production and resource use efficiency.

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Yp and Yw are defined by crop species, climate, soil type and water supply, and thus are highly variable among and within regions. The exploitable yield gap (Yg) is the difference between current average farm yields and Yp or Yw (van Ittersum and Rabbinge, 1997; Lobell et al., 2009). Taken together, Yp, Yw, Yg and WP determine production potential with available land and water resources. These data are required to identify regions with greatest potential to increase food supply and water use efficiency; serve as a guide for research prioritization; provide input to economic global models (either computable general equilibrium models or partial equilibrium or agricultural sector models) that assess food security and land use; and evaluate impact of climate change and other issues that deal with water, food and weather.

Despite the global importance of this information, previous efforts to estimate Yp and Yg lack agronomic relevance and have used methods that are not transparent, geospatially explicit and/or reproducible. This deficiency provides a tremendous opportunity for a coordinated international research effort to establish a Global Yield Gap and Water Productivity Atlas for the major food crops within the next three years. Some of the methods used will build on initial protocols developed at the University of Nebraska under a project funded by the Bill & Melinda Gates Foundation. The atlas will use a "bottom-up" approach that begins with local knowledge of crop and soil management within the constraints imposed by existing cropping systems, combined with global databases on soil type and long-term weather data for each of the world's major food production areas. It will utilize these data in conjunction with robust crop simulation models and a geographic information system to produce detailed maps and an associated database that will be publicly available through the Robert B. Daugherty Water for Food Institute and collaborating institutions.

Yield gaps in Africa

Ken Giller
Wageningen University, the Netherlands

The dominant narrative concerning agriculture in Africa is one of poverty and hunger, caused by over-population, poor agricultural productivity and drought. But Africa is a huge continent with climates, soils, cultures and farming systems that reflect as much diversity as global agriculture. Production systems range from intensive, commercial agriculture to slash and burn. In this paper I discuss the current state of knowledge on yield gaps in Africa and their underlying causes. Apart from the major cereal grains – maize, rice and wheat – the small grains – sorghum and millet – form a major part of the staple food. Other staple foods are highland banana, cassava and other root crops.

Recent research shows that poor and declining soil fertility in the absence of substantial fertilizer use is a major cause of the yield gap in most cropping systems. Much of the information available on yield gaps in Africa pertains to maize and rice. I present an empirical approach based on boundary-line analysis that can be used to unravel the contribution of different factors to the yield gap. This method has been employed recently in projects led by the International Institute of Tropical Agriculture with some surprising results. Even for cassava, which is said to grow on the poorest soils, the principal cause of the yield gap was nutrient constraints due to poor soils and absence of fertilizer use. A multi-location study in Uganda

on highland banana showed that current yields are double those normally reported at the national level; again, soil fertility is the binding constraint on production, while most research attention has been focused on biotic constraints (pests and diseases). Much greater attention to understanding yield gaps in Africa is needed to better guide research and development initiatives.

Water productivity gaps between farmer and attainable yields across sunflower growing regions of Argentina

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Key words: reporting district yields, comparative yield trials, individual field yields

Gaps between attainable yields (derived from comparative yield trial data) and farmer yields (derived from reporting district [county] data) were computed for eight regions of Argentina in which sunflower is grown under rainfed conditions, using BLUE values for both variables estimated from 5 to 9 years of data per region. These gaps were significant ($p = 0.05$ to $p = 0.001$) for all regions and ranged from 0.37 to 1.18 t ha^{-1} across regions, for a country average of 0.75 t ha^{-1} , equivalent to 41% of the mean country yield of 1.85 t ha^{-1}. Individual field yields were available for five regions, and gaps estimated using this variable were smaller than reporting district gaps in three regions (but never nil). Mean yields for the top decile of comparative yield trial data ranged from 3.2 to 4.2 t ha^{-1} across regions, and the highest yields for this decile ranged from 3.9 to 4.8 t ha^{-1}. A notable feature of both individual field and comparative yield trial data was their variability. The mean relative contribution of the trial effect to non-error variance exceeded 89% across regions, dominating the contributions of genotype and of genotype-by-trial effects. We conclude that the farmer/attainable yield gap for this crop justifies further research into its causes, aimed at reducing regional gaps, and that mean comparative yield trial data provide a good benchmark for attainable yields, of greater practical value than mean trial top decile yields or the highest recorded value for the last variable.

Water productivity in Pioneer maize: Past, present and future

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Pioneer Hi-Bred International Inc.

Key words: maize, drought, molecular breeding, crop modeling

Web link: www.pioneer.com

Drought is ubiquitous to farming systems in North America and is often severe enough to reduce maize yields. Improving water productivity will be required to increase food production and farm income. A retrospective analysis using Duvick's ERA hybrids demonstrates that water productivity has increased in response to selection for yield. Physiological studies suggest that multiple modes of action have contributed to improved drought tolerance and water productivity in Pioneer maize. Modern maize tends to capture more water and allocates more resources to support ear growth over canopy growth. This result implies the need to develop novel methodologies to deal with this multitude of adaptive traits, tradeoffs

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among traits, and associated complexity arising from multiple interactions between traits, germplasm and environment. The application of a set of such methodologies, the AYT™ and EnClass® systems, and managed environments led to the creation of AQUAmax® hybrids with higher productivity in water-limited conditions, compared to competitive check hybrids. Crop growth and breeding simulation and high throughput phenotyping technologies will enable further understanding of the germplasm, thus managing the complexity associated with bringing multiple modes of action together to continue improving water productivity and yield under drought stress.

Insights gained from 35 years of research on soybean response to water scarcity and water abundance

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University of Nebraska–Lincoln

Key words: soybean, drought, irrigation, water-productivity

Web link: http://www.hprcc3.unl.edu/soywater/index.html

The relationship between crop biomass (BM) and crop transpiration (T) is highly linear. Plants acquire carbon dioxide (CO_2) for photosynthetic carboxylation through open leaf pores (i.e., stomata), allowing water (H_2O) inside the humid leaf to escape (i.e., transpire) to the atmosphere. The proportionality of that exchange – CO_2 influx / H_2O efflux – is termed *biomass water use efficiency* (WUE_b). The linearity between BM and T is given by the equation: BM = WUE_b x T. The seed fraction of BM is the harvest index (HI), so the linear relationship between seed yield (SY) and T is: SY = WUE_b x T x HI. This equation makes it clear that if we are to enhance crop seed yield, we must increase T and/or increase WUE. To enhance crop T, more water must be provided via improved crop management that will (1) capture and store more of the off- and in-season precipitation, and/or (2) lead to less soil water loss via direct evaporation (E). Enhancing the WUE term in the above equations, however, requires manipulation of the CO_2 / H_2O ratio, which means using breeding, genetics, genomics or transgenic approaches to increase the WUE numerator (i.e., carboxylation) or decrease the denominator (i.e., transpiration). In this presentation, I will highlight some of the opportunities that exist for genotypic improvement in WUE, describe some of the major obstacles to improvement and, along the way, point out how hubris has frequently led to ideas whose hype-to-reality ratio is closer to infinity than to unity.

Using crop models to estimate yield gaps and water productivity

Haishun Yang
Monsanto Co.

Estimation of yield gaps and water productivity is critical for improving crop management. Using the Hybrid-Maize simulation model (http://www.hybridmaize.unl.edu/), we estimated corn yield potential, yield gaps and boundary water productivity for South Central Nebraska in the United States. The estimations were based on recent years' factual cropping information (including hybrid maturity, planting date, plant population, irrigation amount), soil texture of top and subsoil and maximum rooting depth,

and multiple-year daily weather data (including maximum and minimum temperature, solar radiation, precipitation, wind speed, relative humidity and reference evapotranspiration). In this region, irrigated corn yield potential was simulated to be 15.4±0.3 Mg ha^{-1} (at 15.5% moisture content), while actual yield in farmers' fields fluctuated around 12 Mg ha^{-1} in recent years. In other words, current actual yield is about 78% of the yield potential, with a yield gap about 3.4 Mg ha^{-1} in irrigated systems. Using simulated corn yield in both irrigated and dryland systems and reported total water input (including growing rainfall and irrigation), boundary water productivity, defined as yield potential per unit of total water input, was estimated to be 27.7±1.8 kg ha^{-1} mm^{-1}, with a yield function of Y = (X-100)*27.7, where Y is yield in kg ha^{-1} and X is water input in mm. Average water productivity, a robust benchmark for crop management, was estimated to be 19.3 kg ha^{-1} mm^{-1}. Analysis of yield gap and water productivity suggests that either irrigation water can be saved by adopting advanced irrigation methods, such as a pivot system, or yield can be improved by better management of factors other than irrigation amount in South Central Nebraska.

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Maximizing Water Use Efficiency in Agriculture

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Challenges in maximizing water use efficiency

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Key words: irrigation efficiency, water productivity, crop yields, deficit irrigation

Web link: http://parlier.ars.usda.gov/default.aspx

Water use efficiency (WUE) defined in agronomic terms is the ratio of the economic yield of a crop and the crop water use described as evapotranspiration, applied or beneficially used water. The presumption is that the crop will not be stressed and the crop water demand will be fully met. The challenges for maximizing water use efficiency can be divided into technical and social. The technical challenges relate to improving plant performance and improving irrigation efficiency. These include an accurate determination of the crop water requirement, knowledge of crop water production functions, proper design, maintenance and operation of irrigation systems to improve distribution uniformity. Irrigation scheduling to meet crop water demand is an important component in improving WUE. An alternative strategy to improve WUE is deficit irrigation, which should result in the same yield with less applied water. However, it requires a high level of management and potential risk. Improved fertilization management also has the potential to improve WUE. The social challenges include the concept that "I already know how to irrigate." In many instances the knowledge of irrigation practice is handed down through the generations and is based on years of experience but not necessarily on a scientific basis. Even though profits are being made, this does not mean the maximum water use efficiency is being achieved. Economic drivers also impact water use efficiency (e.g., water is the least expensive production component; some water is good, a lot is better).

Measuring and estimating evapotranspiration for water management

Ronald L. (Ron) Elliott
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Key words: evapotranspiration, water management, crop coefficient, weather

Methods for measuring evapotranspiration (ET) include soil water balance, Bowen ratio, eddy correlation and remote sensing. Primarily useful in research, these approaches tend to be fairly difficult, expensive and/or time consuming. So for crop water management purposes, it is more common to estimate ET, using the equation: $ET_{crop} = K_c \times ET_{ref}$, where ET_{crop} is the estimated ET of the crop being grown, usually expressed in units of depth of water per unit of time (hundredths of an inch per day or millimeters per day); ET_{ref} is the reference evapotranspiration, which serves as an evaporative index/benchmark and is calculated based on the weather variables that affect ET (air temperature, solar radiation, wind speed, and humidity); and K_c is the crop coefficient, an empirical factor that reflects the type of crop, its growth stage and the soil water status. Crop coefficient information has been developed and published for a variety of crops around the world. To implement an ET-based

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irrigation water management program, one needs to obtain good local weather data from a representative and well maintained weather station (for ETref), have field-specific information on planting dates and crop development (for Kc), calculate ETcrop, measure rainfall and irrigation amounts, and keep track of the soil water balance and make irrigation decisions accordingly. Challenges in adopting this type of water management strategy include the availability of good data, competing demands for the irrigator's time, and the natural tendency to sometimes focus on achieving maximum yields rather than conserving water.

Role of evapotranspiration in water resources assessment and management, crop water productivity, and response of agro-ecosystems functions

Suat Irmak
University of Nebraska–Lincoln

Availability of freshwater resources for agro-ecosystems has been an important issue for the sustainability of agricultural production in the U.S. and around the world. Concerns include increased competition for water resources due to combination of recent drought cycles, as a result of global climate change; over-pumping of groundwater and surface water resources, due to poor irrigation management strategies; degradation of surface and groundwater quality; increasing industrial and environmental development; and expansion of irrigated lands. In the U.S., the quantity of freshwater withdrawn for irrigation in 2000 was estimated at 55.4 billion m^3, which represented 39.7% of the nation's total freshwater use (USGS, 2000) for all off-stream categories, including public supply, domestic, livestock, aquaculture, industrial, mining and thermoelectric power generation. In terms of daily use, of the 1.31 billion m^3 d^{-1} freshwater used daily in the U.S., 0.52 billion m^3 d^{-1} was used for irrigation (Hutson et al., 2004). Thus, withdrawal of freshwater resources for irrigation plays a critical role in water balances.

Water use efficiency (crop water productivity, CWP) and accurate quantification of evapotranspiration in irrigated and rainfed agriculture have become more important issues with the increase in irrigated lands, increasing prices of inputs for agro-ecosystem production, and availability of less irrigation water than required for maximum production in many parts of the U.S. and around the world. Evapotranspiration, the combination of evaporation from the surface and water loss through plant stomata, is the largest water balance variable in many watersheds. Accurate estimation of ET is critical to determine the CWP dynamics of any production system and necessary to better utilize water resources through well-designed water resources management programs. A reliable estimate of evapotranspiration also is vital to develop criteria for in-season water management, water allocations, long-term estimates of availability of water supply, demand and use, design and management of water management infrastructures, and to assess the impact of land use and management changes on water balances. It also plays a crucial role in determining crop production functions. Despite its crucial importance, a network of actual evapotranspiration measurement infrastructure does not exist to continuously provide water resources policymakers, planners, regulators and users with short- and long-term and improved evapotranspiration (latent heat flux) and other

associated surface energy fluxes, including sensible heat, incoming and outgoing shortwave and longwave radiation, net radiation, albedo, soil heat flux, and soil moisture data for various agro-ecosystems, including various irrigated and rainfed croplands.

This presentation describes: 1) the importance of evapotranspiration in water resources management; 2) the critical relationships between crop water productivity in irrigated and rainfed agriculture, and 3) the functions of the Nebraska Water and Energy Flux Measurement Modeling and Research Network (NEBFLUX), one of the largest and most comprehensive evapotranspiration, plant physiology, soil moisture, microclimate measurements networks in the U.S.

Advances in irrigation technology

Derrel Martin
University of Nebraska–Lincoln

Some agricultural challenges are well known: providing larger and healthier food supplies, supplying the biofuels industry, protecting the quality of water supplies and ecosystems, and conserving water resources. We also face uncertain and changing climatic, economic and regulatory conditions. We must develop a sustainable system that merges research with producer implementation and has widespread societal acceptance. We often encapsulate this challenge as improving the water use efficiency (WUE) and look to technology for solutions. WUE can be quantified as the amount of harvested product per unit of irrigation water withdrawn from a source. We must dissect water use efficiency into components to focus on inter-disciplinary gains needed to enhance water use.

Water use efficiency (WUE) can be described by:

$$WUE = \frac{Yield_i - Yield_r}{Water\ Withdrawal}$$

$$= \frac{Yield_i - Yield_r}{T_i - T_r} \times \frac{T_i - T_r}{ET_i - ET_r} \times \frac{ET_i - ET_r}{RZ_{Stored}} \times \frac{RZ_{Stored}}{Irrigation} \quad \frac{Irrigation}{Withdrawal}$$

where T is transpiration, ET is evapotranspiration, RZstored is water stored in the root zone, and subscripts i and r represent irrigated and rainfed conditions. Increasing yield per unit of transpiration involves advances in genetic capability and agronomic practices to achieve the yield potential. Increasing the amount of transpiration per unit of evapotranspiration involves reduction of nonbeneficial evaporation and/or transpiration through better farming practices, such as minimum tillage and precise irrigation control. Increasing evapotranspiration from water stored in the root zone requires better year-round irrigation scheduling and management. Storing a higher fraction of irrigation in the root zone involves improved irrigation systems and more precise water control. Finally, the conveyance efficiency of the combined irrigation system determines the amount of diverted or pumped water that is applied to the field. Advances in irrigation technology are helping to increase the last four terms of the water use efficiency equation. Advances in water modeling allow us to better partition withdrawn water into consumptive use, recharge and/or return flow to focus on watershed and field-scale impacts.

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Sustainable high yields on poorly drained soils

R. Wayne Skaggs
North Carolina State University

Key words: drainage, irrigation, water quality, DRAINMOD

About 30% of the world's cropland requires artificial or improved drainage for sustainable agricultural production. In humid regions, drainage is needed to provide traffickable conditions for farm operations and to protect crops from excessive saturation. In arid and semi-arid regions, drainage is required to prevent the buildup of soil salinity and the loss of millions of acres of highly productive irrigated agricultural lands. These same drainage systems may have negative impacts on the environment downstream as they typically increase the loss of soluble constituents, such as nitrogen, salts and trace elements, causing serious water quality problems in some cases. For long-term sustainability, drainage and irrigation systems must be designed and managed to address both agricultural production and off-site impacts. A simulation study was conducted to evaluate drainage and irrigation alternatives for producing high, sustainable corn yields on a poorly drained Portsmouth soil in eastern North Carolina. Results for a 35-year period of weather records indicated that it would not be profitable to farm this soil without improved drainage. Subsurface drains 1.2 m deep and 40 m apart increased predicted corn yields to 77% of the yield potential. Yield losses due to dry soil conditions averaged 23% of the yield potential over the long term, but varied from 0 to 50% year-to-year. Irrigation has increased predicted yields to more than 97% of potential, but must be managed carefully to avoid exacerbating problems with excessive soil water. In some years rainfall is sufficient for crop needs and the best use of an expensive irrigation system is to allow it to rest idle in the field. A better alternative for reducing drought stress and increasing long-term sustainable yields for poorly drained soils in this region appears to be development of soil amendments and genetic manipulation to increase root depths. Results of simulations indicated that, without irrigation, average yields could be increased to over 90% of potential by increasing effective root depths from 30 to 60 cm.

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Evaluation of Aquifer Resources in Sub-Saharan Africa

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Bridget Scanlon
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John Gates, Moderator
Assistant Professor of Earth and Atmospheric Sciences, University of Nebraska–Lincoln

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Impact of land use and climate changes on large sedimentary aquifers, West Africa

Guillaume Favreau
Abdou Moumouni University, Niger

Key words: groundwater, semiarid, nitrate

Web links: http://en.ird.fr/, http://www.hydrosciences.org

The semiarid belt south of the Sahara Desert holds some of the largest aquifers in Africa. Most of these aquifers, a few hundred km^2 in size, represent transboundary groundwater resources. Dramatic changes in land use, from natural savannah to rainfed cropping, have occurred in response to a three-fold increase in population since the mid-20th century. Surface waters are limited in time and space and are highly sensitive to drought periods. Long-term groundwater surveys are scarce but urgently needed to estimate the impact of regional changes on aquifers. Case studies from the Iullemmeden (IB, Niger) and Lake Chad (LC) aquifers show that the indirect impacts of land use on water quantity and quality are much greater than the direct impact of climate variability.

The water table balances have been stable, slightly declining (LC) or rising (IB) over the last decades. Crossing results from various methods showed that groundwater recharge occurs mostly by direct percolation through sandy layers in the LC aquifer, whereas focused recharge through ponds and gullies is dominant in the IB aquifer. Land clearing has increased runoff and focused recharge and the water table has been rising in the IB aquifer, whereas the water table response to climate and land surface changes is delayed in the LC aquifer. In both aquifers, leaching of natural soil nitrogen to the aquifer was shown to occur in response to land clearing. A better understanding of groundwater recharge processes is needed to locally adapt management strategies for sustainable use of shared aquifer resources in West Africa.

What geophysics can do for hydrology (and vice versa)

Ty Ferré
University of Arizona

In this talk, I will briefly present established and emerging geophysical methods that may support improved water resource allocation. I will then discuss the importance of collaboration among stakeholders, hydrologists and geophysicists for planning and interpreting hydrogeophysical investigations in support of decision-making under uncertainty.

Investigating groundwater recharge and climate change in Northern Senegal using vadose zone information

Cheikh B. Gaye
Cheikh Anta Diop University, Senegal

Key words: groundwater recharge, vadose zone, Senegal

Interstitial waters from the unsaturated zone of the coastal Quaternary aquifer in northwest Senegal have been extracted to investigate groundwater recharge and recharge history using

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chemical and isotopic methods. Mean direct recharge rates ranging from 10 mm/yr-1 to 87 mm/yr-1 were measured using chloride mass balance. Chloride accumulation has been used to estimate timescales. At the Louga research site, the profiles show Cl accumulation equivalent to up to 400 years' storage in the unsaturated zone. The oscillations in the Cl profiles act as an evaporation record and therefore a record of alternating periods of wet and dry years, confirming the value of the Cl profile as a high resolution proxy of climate variability over the decade to millennial scale. Changes in climatic events are also indicated by the deuterium profile, which reflects the same trends shown by chloride.

Mapping groundwater resilience in Africa

Alan MacDonald
British Geological Survey, U.K.

Web link: http://www.bgs.ac.uk/staff/profiles/0985.html

Groundwater provides most of the domestic water in rural Africa and may have a critical role to play in poverty reduction and climate change adaptation through increased use for irrigation. However, before new policies are developed and programs implemented, increased evidence is required on the spatial distribution of groundwater resources and how resilient they are to climate change. This presentation discusses the results of research led by BGS (funded by the U.K. Department for International Development) to provide quantitative information on groundwater resources for Africa.

Continent-wide maps of groundwater storage and aquifer productivity have been developed by collating and reviewing available hydrogeological maps and aquifer studies for Africa. Field studies from three case studies (Nigeria/Mali, Uganda/Tanzania and Ethiopia) examined the resilience of hand pump supplies and larger irrigation/town supplies, as well as the links between access to water and poverty reduction. It is clear from the research that groundwater possesses a high resilience to climate change in Africa and will/should be central to adaptation strategies. Increasing access to reliable improved groundwater supplies based on hand pumps is likely to be highly successful. However, building strategies that depend on the availability of widespread more highly reliable yields from groundwater is likely to be problematic and will require careful consideration of the local hydrogeological conditions.

Spatial analysis for the promotion of micro irrigation technologies to small scale farmers in Zambia

Lucy Pieterse
International Development Enterprises (IDE)

IDE creates income opportunities for small-scale farmers. In Zambia, the Rural Prosperity Initiative promotes micro-irrigation technologies that allow farmers to produce high value crops during the dry season. These include manual pumps that can lift water from a maximum depth of around 18 m, usually fitted on the large diameter hand dug wells that are common in rural areas. Zambia has abundant surface and groundwater; however, accurate characterization of these resources is necessary to encourage their sustainable utilization. Research in the rural areas has been focused largely on a potable water supply for which groundwater

is often the only source. GIS products that describe the temporal and spatial variation in shallow groundwater are needed to aid the planning and monitoring of projects that promote irrigated agriculture. IDE started a well monitoring program in 2010 in which farmers record changes in the depth to water throughout the year. The large network of IDE farmers across the country, as well as the organization's use of ICT to improve data flow through this network, puts IDE in a good position to provide support for hydrogeological research agendas.

GRACE satellite shows increasing groundwater resources in West Africa

Bridget R. Scanlon
University of Texas at Austin

Web link: http://www.beg.utexas.edu/cswr

While many aquifers are being depleted globally, here we show increasing groundwater resources in the Continental Terminal aquifer in West Africa using GRACE satellite data. Groundwater storage has increased 18 mm/yr, equivalent to 3 km^3 over a 150,000 km^2 area during the past eight years. The GRACE results are consistent with ground-based trends, 23 mm/yr over a 10,000 km^2 area near Niamey. Increasing groundwater resources are attributed to enhanced focused recharge through ponds and gullies caused by land use change from natural savannah to millet crops. This increase in groundwater resources provides an opportunity to expand irrigation in this region and increase agricultural productivity.

Thoughts for the Water for Food Institute

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Thoughts for the Water for Food Institute

Closing Panel

Eugene Glock
Producer, Cedar Bell Farms, Nebraska

Simi Kamal
Chairperson and CEO, Hisaar Foundation, Pakistan

Robert Meaney
Senior Vice President, Valmont Industries Inc.

Mick Mwala
Dean, School of Natural Resources, University of Zambia

Prem S. Paul, Moderator
Vice Chancellor for Research and Economic Development, University of Nebraska–Lincoln

This panel discussion addressed conference topics, raised issues that researchers, policymakers, producers and organizations must consider, and suggested goals and priorities for the Robert B. Daugherty Water for Food Institute.

Eugene Glock, Cedar Bell Farms

Eugene Glock said he was struck that in an informal poll, the majority of attendees indicated they believe current technology can meet the growing demand for food. "If we've got all the knowledge we need to address it, then there's a complete disconnect between the knowledge and the use of that knowledge," he said.

He cited tradition and governmental interference as two obstacles to meeting demand. Subsistence agriculture must follow the U.S.'s example and become more efficient through larger farms, he said, but warned that if one person now feeds 100 people, the other 99 people need to find other work. "I think that's a challenge that has not been addressed adequately yet," Glock said. "And when it is, we may see greater acceptance of the methodology that is available to address this food problem."

Additionally, he said, too many U.S. policies restrict farmers instead of giving them incentives to adopt beneficial practices, citing farm subsidies as an example of "a senseless policy" that could instead encourage greater water use efficiency. Glock urged the scientific community to overcome its reluctance to engage policymakers and to help them understand how to improve food production.

Robert Meaney and Simi Kamal

Simi Kamal, Hisaar Foundation, Pakistan

Simi Kamal stressed the need to include marginalized people, particularly women, in future discussions. "If women were the leaders in agriculture and livestock raising and they took decisions about water for food, would the debate be different? Would their priorities be different? Would we have something else on the ground?" she asked.

Although international agencies often assume women's water concerns are limited to hygiene, women often don't distinguish between drinking water and water for gardens and food. "They have to feed their families and children. When they fetch water, they fetch water for life – the daily food security that keeps the family going. I think that's something missing from our equation," Kamal said.

Perspectives from the dispossessed and the landless also are missing, she said. What role does government play in giving access to water and establishing water rights for the landless? she asked. And, as new policies raise the value of land and other assets, what happens to the landless or smallholder farmer? "Crucially, we must address the issue of power," Kamal said. The marketplace is influenced by power relations at the local level, between provinces and states, and within international food trade. "The market is not as free as we might think it is," she said.

Kamal urged participants to consider agriculture holistically, as a component of a larger ecosystem. For millions worldwide, food security and a dignified life depend on environmental entitlements, she said, a factor that must be considered when taking water from commonly owned or accessed water resources.

Thoughts for the Water for Food Institute

Robert Meaney, Valmont Industries Inc.

A clear theme that emerged during the conference was the difficulty in finding solutions, Robert Meaney said. The panel addressing the California Delta, for example, demonstrated how deeply California's production agriculture and society are intertwined. Despite the panelists' breadth of knowledge and available resources, "they really don't have a clue where they're going to end up," he said, adding that answers to similar questions worldwide elude many.

Technology and research provide much hope, Meaney said, but he echoed his co-panelists' concerns about the importance of appropriate policies. Poor countries must develop farming technology to increase production, but determining how to employ displaced farmers is a major problem. "Yes, there's the story about how there will be more jobs for them down the road, but how do you make that transition?" he asked.

Today's strong agricultural market works to farmers' advantage, Meaney said. Spiking food prices bring money into rural areas, which can then be used to build roads, schools and other basic infrastructure needed to compete in the marketplace and eventually bring prosperity to rural areas.

The agricultural community must promote the food production business and better articulate these critical issues, he said.

Mick Mwala, University of Zambia

Mick Mwala said he agreed with Eugene Glock that targeting policymakers is critical. Agriculture currently receives little support, he said. However,

Mick Mwala and Eugene Glock

> *"Until we understand the other person's problems, we can't help them with a solution. Because if we interject our solution, we may make the problem worse."*

armed with evidence, researchers can elevate agriculture's importance and influence policymakers in making sound decisions.

Mwala also emphasized the need for partnerships with developing and developed countries, which will allow the Robert B. Daugherty Water for Food Institute to build on diverse strengths. Developed countries have the advantages of qualified staff and research infrastructure; therefore, these nations should be encouraged to continue investing in research. But he cautioned that partners from developing countries have different perspectives and also should be engaged.

He said he is glad the institute has adopted a comprehensive framework that encompasses water usage, education and policy analysis. "To me, those three are key, if we [are] to make any difference," Mwala said.

Questions and Answers

Moderator Prem Paul: ***What was the most significant solution you heard at the conference?***

Robert Meaney said he believes the solution lies in adopting the right frame of mind. Farming is a business, no matter how small the farmer's area. "The people who can make it into a business, those are the people who should go into farming and should become the people who build the [agricultural] sector," Meaney said. Identifying those people is the challenge.

Simi Kamal suggested the solution lies in building a balance between technology and human power, as well as reducing water and food consumption.

Mick Mwala and Eugene Glock said partnerships that bring together diverse strengths to find solutions are needed. Glock said, "Until we understand the other person's problems, we can't help them with a solution. Because if we interject our solution, we may make the problem worse."

Audience question: ***How much should the Daugherty Institute emphasize the social sciences compared to the biological and physical sciences?***

Prem S. Paul said technology is critical to solving food and water security. "But if the technologies are developed without participation of the social sciences, they'll sit on the shelf and may not get adopted. How do we change behavior?" He added that the social sciences are critical to answering that question. The institute engages the entire University of Nebraska system to incorporate a range of expertise.

Audience question: ***How can we give more attention to gender equity?***

Many assume women lack a role in agriculture, Kamal said. But in many countries, women are

Thoughts for the Water for Food Institute

> *"Our goals are to make as much impact as possible, but not alone, through strategic partners."*

heavily involved in farming and in water management. However, she said, because women's labor is often unpaid, it isn't counted toward a region's economic contributions, rendering women invisible.

Changing institutional structures that keep women hidden are needed, she said. For example, some European and South American countries measure gross economic product (GEP), which, unlike gross domestic product, counts women's unpaid labor. GEP brings women greater visibility and influence, Kamal said. She suggested that the Daugherty Institute start a team on gender, water and food.

Audience question: ***What is the institute's role in changing U.S. agricultural policy and spreading those policies worldwide?***

Glock said just as U.S. policies give oil companies and wind farms tax breaks for energy production, similar incentives are needed to encourage water efficiency. The institute can provide information that policymakers need to pass appropriate legislation, he said.

He urged the institute to help countries obtain and disseminate the information they need to convince decision-makers to reform agricultural policies. "Maybe if enough people have the courage to do it and people see the results, then we'll see something good come from it," he said.

Audience question: ***What are the institute's short-term goals and priorities?***

Paul listed several short-term goals, including hiring an executive director, developing partnerships and hiring additional expertise. "Our goals are to make as much impact as possible, but not alone, through strategic partners," he said.

Mwala said the institute should include promoting itself as another short-term goal.

Audience question: ***How can agriculture engage and partner with environmental interests and urban users, two additional key groups competing for water?***

Most freshwater is used for agriculture, Kamal said. But while many institutions examine and advocate for the environment, industries, cities and other water users, only the Food and Agriculture Organization of the United Nations (FAO) addresses water for food. That underscores the need for the Daugherty Institute, she said, which should, at some point, link with these other organizations.

In closing, Paul said he was glad to hear participants' optimism that global food security is achievable. But he acknowledged that the optimism came with the caveat that many challenges lie ahead. Two key messages that emerged during the conference for meeting those challenges were the essential need for partnerships and the importance of engaging policy and governance.

Prem S. Paul moderates the closing panel.

Afterword

It is gratifying how quickly the Robert B. Daugherty Water for Food Institute has gained recognition and importance. As the third global Water for Food Conference ends, we are very appreciative of the accomplished experts and participants who have given so much of their time to the conference and who have provided advice to the institute.

The presentations and discussions we heard at the 2011 conference demonstrate the need for additional research, policy analysis, education and dialogue on this critically important challenge of feeding a growing population with finite water supplies. The conference also has brought to the fore the need for more funding in this arena. The challenge is great and the resources being invested do not match the need for solutions.

This is why partnerships are so critical. Only working together can we do the work that needs to be done. We are very excited about the partnerships we are building with UNESCO-IHE, Harvard University, U.S. Agency for International Development (USAID) and the private sector, and we look forward to similar collaborations in focused areas.

On a personal level, I want to express my appreciation to Jeff Raikes, Mogens Bay, James B. Milliken and Harvey Perlman for their energy, vision and support for the conference and the Daugherty Water for Food Institute. I also want to thank the Bill & Melinda Gates Foundation, the Robert B. Daugherty Charitable Foundation and Monsanto Co. for making the conference possible. Most importantly, I want to recognize the support of the citizens of Nebraska who have embraced the institute, recognizing the important work it will do in Nebraska and globally.

Sincerely,

Prem S. Paul
Vice Chancellor for Research and Economic Development, University of Nebraska–Lincoln

Meet the Daugherty Institute's Founding Director

Roberto Lenton, one of the world's foremost experts in water management and development, is the founding director of the Robert B. Daugherty Water for Food Institute at the University of Nebraska.


Roberto Lenton

NU President James B. Milliken announced Lenton's hiring in August. Lenton began his appointment Feb. 1, 2012, after completing his responsibilities as chair of the independent World Bank Inspection Panel. He had served as chair since 2009 and remains a panel member until August 2012. Lenton also holds an appointment as professor of biological systems engineering at the University of Nebraska–Lincoln.

"Roberto Lenton is the ideal person to lead the Daugherty Institute as its founding director," Milliken said. "His experience in water management, food security, sustainable agriculture and responsible use of resources is exceptional. As important, he shares our vision for the institute and its potential to have an impact on the world."

Lenton helped establish and then served as director general of the International Water Management Institute (IWMI) in Sri Lanka from 1987 to 1994. Under his leadership, IWMI grew from a small project-based organization to a major institute employing more than 300 people in 10 countries with an annual budget of over $10 million.

"I am very excited by the opportunity to lead to build on these strong foundations and enable the Daugherty Water for Food Institute in fulfilling its commitment to help the world use its limited freshwater resources effectively and ensure food security for current and future generations," Lenton said.

Lenton said that the Robert B. Daugherty Water for Food Institute has much to build on: its base at a leading land grant university with a strong tradition of practical application of scientific knowledge; its location in the state of Nebraska, known as an innovator of good policies and practices in agricultural water management; the enormous talent of its faculty and research staff who have a long track record of addressing water and food security issues from a variety of disciplinary perspectives; its strong convening power, as illustrated by the annual Water for Food Conferences that have begun to shape the debate on this critical issue; and the generous founding gift from the Robert B. Daugherty Foundation that will enable the institute to get off to a rapid start.

A citizen of Argentina with degrees from the University of Buenos Aires and the Massachusetts Institute of Technology, Lenton also was director of the United Nations Development Programme's Sustainable Energy and Environment Division, program officer in the Rural Poverty and Resources program with the Ford Foundation, and an assistant professor at MIT. He also was senior adviser on water at Columbia University's Earth Institute.

"We are fortunate to have been able to attract someone of this caliber and international reputation to the University of Nebraska," Milliken said. "He will help us quickly establish the Daugherty Institute as a global leader in research, education and policy related to water for food."

Poster Competition, Conference Participants and Photos

Appendix

Poster Competition

The 2011 Water for Food Conference included a juried poster competition for graduate students. Forty posters were entered in three key categories that reflected the major conference themes and a general category for other topics related to water for food. Additional posters were submitted by faculty and other partners, and are listed below the students' entries by category. Award winners are pictured with University of Nebraska–Lincoln Chancellor Harvey Perlman.

Online Competition

University of Nebraska faculty served as jurors for an online competition held before the conference. Cash prizes were awarded to:

First Place ($1,500): Yi Peng, UNL, *Remote Sensing of Crop Primary Productivity Using Satellite Data*

Second Place ($1,000): Fauziata Ahmed, UNESCO-IHE Institute for Water Education, Delft, the Netherlands, *Modeling the effect of field management measures on crop yield and implications for food security and virtual water trade in the Volta Basin Countries, West Africa*

Third Place ($750): Saadia Bihmidine, UNL, *Engineering soybean for improved photosynthetic performance, drought tolerance, and yield using C4 enzymes from Cyanobacteria*

Yi Peng, UNL

Fauziata Ahmed, UNESCO-IHE

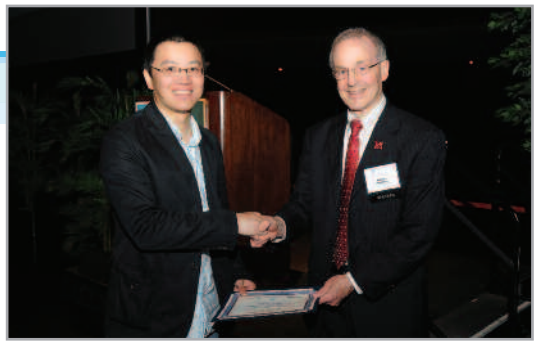
Saadia Bihmidine, UNL

Viewer's Choice Competition

A viewer's choice competition was held at the conference during the poster session. Those registered for the conference voted for the best poster. Cash prizes were awarded to:

Winner ($1,500): Gengxin Ou, UNL, *Modeling the stream-aquifer dynamics using streambed field data in the Lower Platte River*

Honorable Mention ($750): Joana Chan, Kristine Nemec and **Don Pan,** UNL, *Food for Thought for Water for Food: Integrating a Resilient Systems Approach*



Gengxin Ou, UNL

Joana Chan, UNL

General Topic Related to Water for Food

Jurors

Mark Burbach, Richard Ferguson, Lilyan Fulginiti, Kyle Hoagland, Harkamal Walia, Donna Woudenberg and Arthur Zygielbaum, UNL; and **Shawn Gibbs,** University of Nebraska Medical Center

Graduate Students

Maitham Al-Sammak, UNL, *The Role of BMAA (Algal Neurotoxin) in Freshwater and Marine Environments*

Joana Chan, Kristine Nemec and **Don Pan,** UNL, *Food for Thought for Water for Food: Integrating a Resilient Systems Approach*

Laura Christianson, Iowa State University, *A Path to a Nitrate Solution: Enhanced Denitrification Treatment in a Global Context*

Jason DeBoer, Nebraska Cooperative Fish and Wildlife Research Unit, UNL, *Water, walleye and corn: a conundrum in an arid landscape*

Zelike Agide Dejen, UNESCO-IHE Institute for Water Education, Delft, the Netherlands, *Comparative Assessment and Farmers Utility Analysis in Community-managed Irrigation Schemes in Ethiopia*

Eric Hunt, UNL, *Spatiotemporal analysis of soil moisture variability within and between three agroecosystems over eight growing seasons*

Poster Competition

Ann Hunter-Pirtle, UNL, *Groundwater depletion over time in Nebraska counties*

Deepti Joshi, UNL, Water Quest: *A Volunteered Geographic Information (VGI) System for Data Collection and Synergistic Understanding of Water Resources, Human Activities, and Food Supply*

Aziza Kibonge, UNL, *Agricultural Productivity, Climate Change and Water Availability in Sub-Saharan Africa*

Ruopu Li, UNL, *Assessment of 2011 Sendai Earthquake/Tsunami Impacts on Coastal Agriculture Using Remote Sensing and Geographic Information Systems*

Zhongtian Li, UNL, *Bacterial community dynamics in a biologically active carbon (BAC) reactor capable of 17β-estradiol biodegradation for drinking water treatment*

Joseph Msanne, UNL, *Characterization of abiotic stress-responsive* Arabidopsis thaliana *RD29A and RD29B genes and evaluation of transgenes*

Denis Mutiibwa, UNL, *Identifying Fingerprints of Land Use/Land Cover Change on Climate Change in the High Plains*

Pamela Pena, UNL, *Modulating Nitrogen Flux in Sorghum and Wheat*

Yi Peng, UNL, *Remote Sensing of Crop Primary Productivity Using Satellite Data*

Gwendolyn Ryskamp, University of Nebraska at Omaha, *Increasing environmental literacy and water quality awareness in the Elkhorn River Basin through community based scientific research*

Jonathan Sallach, UNL, *Potential for Antibiotic Uptake by Soil and Crops from Irrigation with Recycled Water*

Vivek Sharma, UNL, *Quantification and spatial interpolation of reference and actual evapotranspiration, and net irrigation requirements for maize and soybean across Nebraska*

Vivek Sharma, UNL, *Application of GIS and geographically-weighted regression to evaluate the spatial non-stationarity relationships between precipitations vs. irrigated and rainfed maize and soybean yields*

Prabhakar Shrestha, UNL, *Personological Mapping of Farmers in Nebraska and Kansas*

Manmeet Singh, UNL, *Monitoring Ds Transposition in the Soybean Genome*

Chris Thompson, UNL, *The Impact of Rising Grain Prices on the Value and Temporal Use of Water*

Federico Trindade, UNL, *Climate Impact on Agricultural Efficiency*

Yuping Zhang, UNL, *Accumulation of Antibiotic Resistant Salmonella in Lettuce after Irrigation Using Recycled Water*

Kathryn Zook, Duke University, *Paths to Solutions: A Case Study of Ground Water Use in Arkansas Rice Production*

Other Entries

Lisa Durso, USDA-Agricultural Research Service, Lincoln, Neb., *Assessing the Performance of a Vegetative Treatment System to Reduce Pathogens in Feedlot Runoff*

David Toll, NASA/Goddard Space Flight Center, Greenbelt, Md., *NASA Water Resources Program for Improved Water Management and Food Security*

Groundwater and Surface Water Hydrology

Jurors

Ed Harvey and **Vitaly Zlotnik,** UNL

Graduate Students

Chunmei Bai, UNL, *Multi-dimensional Modeling Transport of Fullerene (C60) Nanoparticles in the Subsurface Environment*

Isa Kabenge, UNL, *Canopy Resistance, Plant Physiological Parameters, Transpiration and Evaporation of a Phragmites-dominated Riparian Plant Community in the Platte River Basin, Nebraska, USA*

Ruopu Li, UNL, *Integrating LiDAR Technology into Agricultural Wetland Conservation: A Case Study in the Upper Sand Creek Watershed*

Danielle Moore, UNL, *Hydroinformatics: Data Integration in Hydrologic Information Systems for Analysis, Visualization and Modeling in a Multi-State Watershed*

Gengxin Ou, UNL, *Modeling the stream-aquifer dynamics using streambed field data in the Lower Platte River*

Pramod Pandey, Iowa State University, *Predicting rainwater harvesting potential in field-scale reservoir systems for supplemental irrigation to crop*

Leiming Zhao, UNL, *Building 3-D Wetland-Agricultural Geodatabase in South Central Nebraska*

Other Entries

Sukarma Thareja and **Siddhartha Choudhury,** Chhatrapati Shahu Ji Maharaj University, Kanpur, India, *Multivariate Analysis of Water Quality of Ganga River*

Poster Competition

Maximizing Water Use Efficiency In Agriculture

Jurors

Ann Bleed, Dean Eisenhauer and **Greg Kruger,** UNL

Graduate Students

Kendall DeJonge, Colorado State University, *Yield Potential and Water Use in Irrigated Cropping Systems: Field Experiments, Instrumentation, and Modeling*

Koffi Djaman, UNL, *Crop Water Productivity, crop evapotranspiration, deficit irrigation stress index, and plant growth and yield parameters of maize (Zea mays L.) under full and deficit irrigation*

Leonard Rusinamhodzi, Wageningen University, the Netherlands, *Long-term maize-pigeonpea inter-cropping increases rainfall infiltration in a degraded sandy soil in central Mozambique*

Sanjay Satpute, Indian Agricultural Research Institute, New Delhi, India, *Modeling of phosphorus distribution under different drip fertigation strategies*

Sonisa Sharma, UNL, *Comparison of photosynthetic performance of Zea mays (corn) grown under different nitrogen levels and gradual soil water depletion*

Benjamin Stewart, UNL, *The Bluehouse: A Conceptual Design to Cleanse Polluted Water and Produce Food in Resource-Ravaged Locales*

Sivasakthi Sundaram, Indian Agricultural Research Institute, New Delhi, India, *Nitrogen management in garlic cultivation under drip irrigation using numerical modeling*

Samuel J. Sutanto, UNESCO-IHE Institute for Water Education, Delft, the Netherlands, *Partitioning Soil Evaporation and Transpiration for Plant Water Use Efficiency using Hydrometric Measurements and Stable Isotope Techniques*

Other Entries

Bama Nati Aïssata Delphine, Cheikh Anta Diop University, Dakar, Senegal, *Effect of water regimes on salinization and productivity of rice in the lowlands of Sine Saloum in Senegal*

Jake LaRue, Valmont Irrigation Inc., Omaha, Neb., *Field Scale Results Using Variable Rate Irrigation for the Production of Rice with a Center Pivot*

Jennifer (Jenny) Rees, UNL, *Comparison of Water Use and Crop Water Use Efficiency of Maize, Sorghum and Soybean in Nebraska*

Kari Skaggs, UNL, *Getting Extreme: The Intricacies of Historical Temperature Change Effects on Agriculture*

Reducing the Yield Gap: Biophysics, Technologies, Policies and Economics

Juror

Patricio Grassini, UNL

Graduate Students

Fauziata Ahmed, UNESCO-IHE Institute for Water Education, Delft, the Netherlands, *Modelling the effect of field management measures on crop yield and implications for food security and virtual water trade in the Volta Basin Countries, West Africa*

Saadia Bihmidine, UNL, *Engineering soybean for improved photosynthetic performance, drought tolerance, and yield using C4 enzymes from Cyanobacteria*

Mohammad Reza Hosseini, UNESCO-IHE Institute for Water Education, Delft, the Netherlands, *Optimizing agricultural production under water scarcity in Fars province, Iran*

Kepifri Lakoh, UNL, *Analysis of the Effects of Soil Organic Matter (SOM) on Agricultural Productivity (Making the Case for Water Conservation and Soil Carbon Sequestration)*

Conference Participants

Abbreviation Key:

ICARDA: International Center for Agricultural Research in the Dry Areas
IDE: International Development Enterprises
IWMI: International Water Management Institute
OWWDSE: Oromia Water Works Design and Supervision Enterprise
UNESCO-IHE: United Nations Educational, Scientific and Cultural Organization-International Institute for Infrastructural, Hydraulic and Environmental Engineering
UNK: University of Nebraska at Kearney
UNL: University of Nebraska–Lincoln
UNMC: University of Nebraska Medical Center
UNO: University of Nebraska at Omaha
USDA-ARS: U.S. Department of Agriculture-Agricultural Research Service
USDA-NASS: U.S. Department of Agriculture-National Agricultural Statistics Service
USDA-NRCS: U.S. Department of Agriculture-Natural Resources Conservation Service

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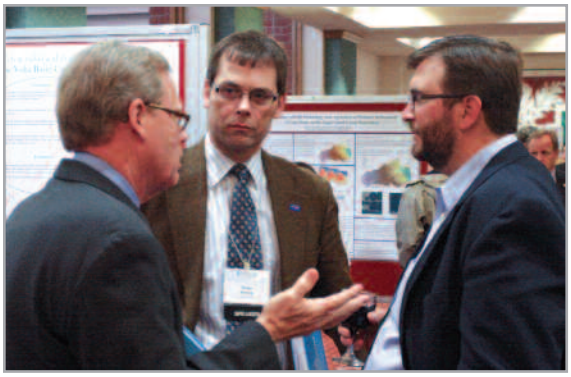
Conference Photos

Jeff Raikes (right) and graduate students

Evening reception



Fred Luckey, Peter Saling and Michael Doane

John Gates

Water Quality Interest Group discussion

Bob Bettger and James Goeke

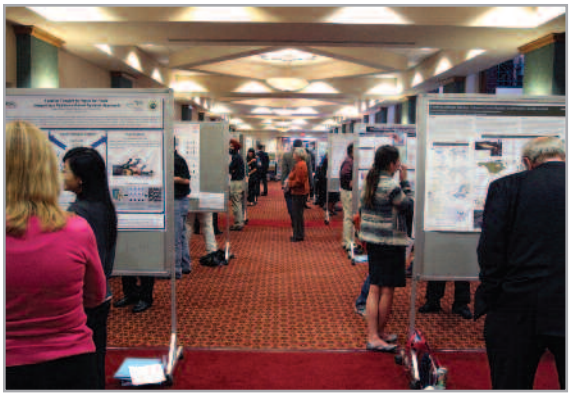
University of Nebraska Regent Jim McClurg and Mogens Bay

Dale Jacobson and Fred Choobineh

James B. Milliken (left) and András Szöllösi-Nagy (center) sign an agreement between the University of Nebraska and UNESCO-IHE Institute for Water Education. Also pictured is Jeff Raikes (right).

Fauziata Ahmed

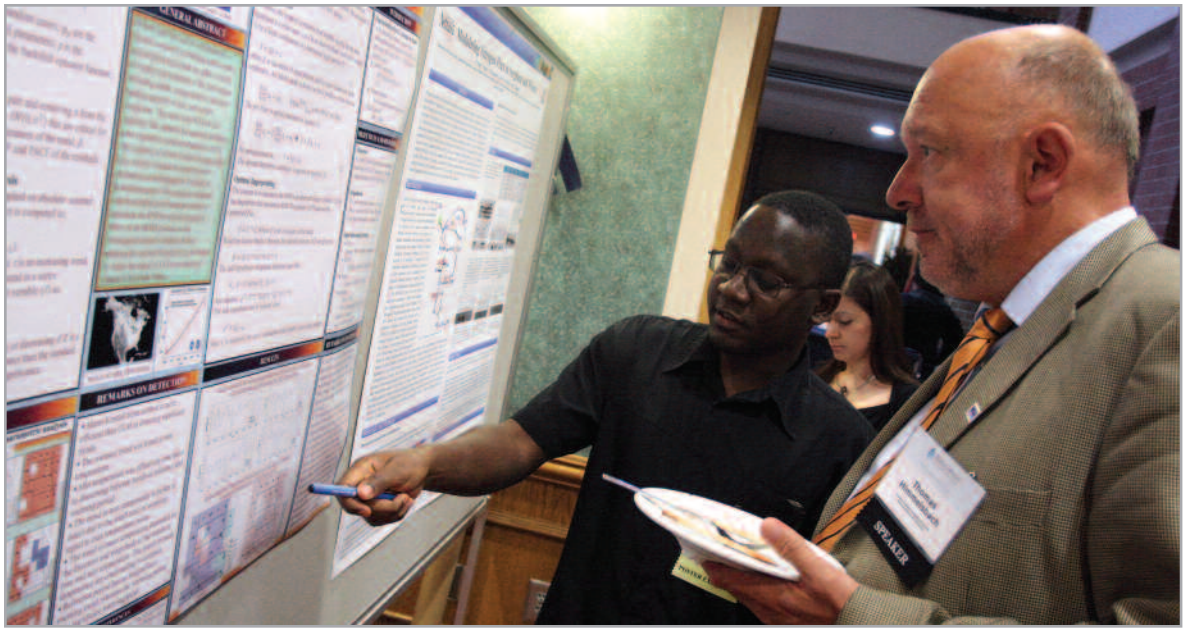
Susan Fritz and Samuel Jonson Sutanto



Juried poster competition

Shashi Verma

Simi Kamal, Sheri Fritz and Ann Bleed



Thomas Himmelsbach views a graduate student's poster

Jerry Stahr

Prem S. Paul (right) and Mick Mwala

Reception

Ag Tour Photos

Ken Cassman

Advanced BioEnergy LLC in Fairmont, Neb.

Modern equipment used by corn and soybean producer David Bruntz of Friend, Neb.

Weber & Sons beef cattle feedlot near Dorchester, Neb.

Feedlot cattle

Learning about operations at Weber & Sons feedlot

O'Neel Farms near Friend, Neb.

Ken Cassman, Pasquale Steduto and other guests tour Advanced BioEnergy LLC.