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Future of Water for Food: Science and Technology Panel

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More Food with Less Water?

Science and Technology Panel

Panelists
Ramesh Kanwar, *Charles F. Curtiss Distinguished Professor and Chair, Agricultural and Biosystems Engineering, Iowa State University*
Brian A. Larkins, *Porterfield Professor of Plant Sciences, University of Arizona; John F. Davidson, Ph.D., and Marian J. Fuller, Ph.D., Chair in Life Sciences, University of Nebraska–Lincoln*
Judith C.N. Lungu, *Dean, School of Agricultural Sciences, University of Zambia*
Vincent Vadez, *Principal Scientist, Head of Crop Physiology Laboratory, International Crops Research Institute for the Semi-Arid Tropics*
Ron Yoder, *Department Head, Biological Systems Engineering, and Associate Director, Agricultural Research Division and Extension, University of Nebraska–Lincoln*

Moderator
Sheri Fritz, *Willa Cather Professor of Geosciences and School of Biological Sciences, University of Nebraska–Lincoln*

The panel explored key issues and challenges in the science and technology of water management to ensure an adequate food supply for the world. Panelists brought many years of experience and perspectives from different areas of expertise. The panelists gave brief overviews of their subject areas and then responded to questions from the audience.

Brian A. Larkins: Drought Tolerant Crops

Brian Larkins is a plant physiologist whose research focuses on regulating seed development in cereal crops and the synthesis of seed storage proteins. Seed storage proteins are the principal determinants of grains protein quality. Larkins' remarks focused on two topics: creating more drought tolerant crops to sustain food production when water is limited, and improving the nutritional value of maize and sorghum to maintain nutritional values if crop yields decrease.

Plant mechanisms for dealing with drought. A drought tolerant crop, Larkins explained, is one with traits that make the plant more *tolerant* to water loss. Wheat, barley and rye *escape* drought by maturing before the summer droughts arrive. Other plants increase their tolerance to drought by producing high concentrations of amino acids or alcohol sugars, which enable cells to retain water. Plants also produce groups of proteins called dehydrins that stabilize the cytoplasm so it is not damaged by water loss. They also create heat shock proteins, key players in the stress response in plants. *Avoidance mechanisms*, such as the leaf rolling exhibited by corn and sorghum during dry periods, are perhaps the most important plant mechanisms to deal with drought. Avoidance mechanisms often involve the cuticle on the leaf; the presence or absence of hairs on the leaf; the length of time the leaf stomata stays open, allowing water to escape by transpiration; and the type of photosynthesis the plant uses.

Current focus of crop research. Don Dubick of Pioneer Hybrids did an experiment in which he took the highest-yielding hybrids Pioneer had produced over a 50-year period and planted them one foot apart. The yield for each hybrid was the same. However, when he planted the hybrids three inches apart, the newest hybrids outperformed the older hybrids. That result, Larkins said, indicates that plant breeders thought they'd been

breeding for increased yields but instead produced plants with an increased tolerance for drought stress caused by crowding.

Much of this research is focused on corn. Corn is worth about $5 billion per year in the U.S. and $13 billion per year worldwide, and drought can cause a 40 to 50 percent reduction in corn yield resulting in major economic impacts. Seed and agricultural biotechnology companies also are focusing on approaches to increasing yield that go beyond traditional plant breeding techniques. They are actively trying to identify key genes and regulatory pathways that activate drought tolerance. In order to do map-based cloning, researchers have completed a very fine mapping of the corn genome to determine what genes and molecular factors have changed as a result of breeding programs. To date, research has shown differences in the expression of hundreds of genes in response to drought conditions, which illustrates the complexity of the genetic regulation of drought response.

However, yield increases have been achieved in corn by using a transgenic approach – taking a single regulatory gene that controls a number of processes that make the plant more drought-tolerant from one species and putting it in another. Researchers also have encoded a protein that increases the plant's protein synthesis capacity. In both of these examples, a change in a single gene increased yields 10 to 15 percent. These experiments indicate that improving drought tolerance does not need to be complex; engineering only a few specific genes can make great improvements. Pioneer Hybrids and Monsanto expect that within the next five years they will release new genetically engineered corn hybrids that increase yields under drought conditions by 15 to 20 percent.

Brian Larkins (foreground) and Sheri Fritz

Another approach Larkins described is engineering drought tolerant crops, such as sorghum and millet, to produce grain with the protein quality and other beneficial properties of corn. Although their flowers are quite different, corn and sorghum are sister crops with a number of similar characteristics. Over many years, CIMMYT, the International Maize and Wheat Improvement Center, has developed a quality-protein maize, which is a high lysine corn that solves the problems present in corn. Pioneer Hybrids is conducting the same type of research on sorghum, with funding from the Bill & Melinda Gates Foundation. "I will simply tell you that it's now possible to produce sorghum that is also high in protein quality and digestibility," Larkins said.

Larkins also expressed excitement about research being conducted by Bruce Hamaker of Purdue University. Hamaker is a food scientist who has been working on finding ways to use corn and sorghum flour to make bread. Bread dough made with wheat flour is viscoelastic so at room temperate it rises as the yeast ferments, producing a typical loaf. Corn flour is not viscoelastic at room temperature. However, adding 1 percent wheat glutenin, or corn starch and corn protein plus 1 percent milk protein, to the corn flour

causes the loaves to rise at room temperature and look like bread. This process has great potential for people who suffer from celiac disease, an allergy to wheat proteins, and for places like Sub-Saharan Africa, where the cost of importing wheat is almost prohibitive, but sorghum is a common crop. "In theory you could accomplish the same thing with genetic engineering by putting in a gene that would add protein to the flour," Larkins said. These are the kinds of advances that can be made by engineering a single gene.

Judith C.N. Lungu: Food and Water Challenges in Africa

Judith C.N. Lungu, an animal physiologist, has specialized in livestock development at the University of Zambia for more than 20 years. She also has worked extensively with the rural farming communities of Zambia and serves on the boards of directors of Women for Change, the Zambian National Bank and the Livestock Development Trust. In her role as dean of the School of Agricultural Sciences at the University of Zambia, she is a leader in the development, coordination and implementation of programs to foster sustainable land and water management.

Lungu's presentation focused on the food and water challenges in Africa. The weather in Africa, Lungu explained, varies a great deal, with the north and south being quite cool. Rainfall distribution also varies greatly from place to place and season to season. The average precipitation in Zambia varies from 700 millimeters to 1,200 millimeters per year. Rainfall also is unreliable. Droughts and floods, which are increasing, affect more than 135 million people each year.

Judith C.N. Lungu

Agriculture and plentiful water, but little irrigation. Although agriculture contributes only 17 to 30 percent of Africa's gross domestic product and about 18 percent of Zambia's gross domestic product, the majority of the population of Sub-Saharan Africa depends on agriculture for its livelihood. This agriculture has very low productivity, less than 1 metric ton per hectare, so at least 60 percent of the growers, the majority of whom are women, are subsistence farmers. "They depend on rainfed agriculture, and in Zambia it comes in four months and the rest of the year it's dry, so some people in the rural areas … are the poorest of the poor. They are in extreme poverty," Lungu said.

The challenge for Africa is how to manage the available resources at local, national and inter-country levels when the precipitation is not dependable and there is little irrigation because the infrastructure is undeveloped. Lungu observed that some of the largest dams in the world, including the Kariba Dam in Zambia and Zimbabwe, and the Aswan Dams, are in Africa. It is said that one-third of the water in southern Africa is found in Zambia, yet only 5 percent of the cultivated land is under irrigation. Although Zambia sits on top of a large aquifer, only 12 percent of the farmers who irrigate rely on groundwater. Unlike some areas of Africa, where the problem is water scarcity, Zambia's problem is lack of infrastructure to use the water. Among those who irrigate are some large-scale farmers with center pivots, many of which were brought from Nebraska. However, most farmers use ditch irrigation. Some small farmers use treadle pumps, which women and children can operate. Close to one hectare of land can be irrigated with a treadle pump.

Adding to the problem is that the population is growing quickly in dryland farming areas, where agricultural productivity is very low. Because of the low productivity in Sub-Saharan Africa, 2.9 million people per year suffer hunger-related deaths.

Africa has a crisis, Lungu said. The water is there, but it's not being utilized. In Zambia more than 500,000 hectares could be irrigated and highly productive. Currently, only about 50,000 hectares are irrigated, and most are planted with perennial crops like sugar cane and coffee, which are not key food staples. Zambia and the rest of Sub-Saharan Africa has a great need for enhanced water use technologies to improve food security.

Environmental problems hinder food production. Other challenges to improving food production in Zambia are unrelated to water. They include soil degradation, decline in the quality of vegetation, and loss of wildlife and biodiversity. People in Zambia traditionally have relied on burning to clear land and cutting to obtain fire wood. These practices degrade the soil.

Addressing Sub-Saharan Africa's issues. Lungu outlined a number of steps needed to address the issues in Sub-Saharan Africa. Researchers need to understand the characteristics of the African climate; inventory water resources; invest in the development of surface and groundwater; and improve the water storage, water harvesting and water production efficiency for both rainfed and irrigated agriculture. Africa needs to provide affordable drinking water supplies so towns do not have to go without water for a week. Stakeholder information systems and participation also must improve so people can make good decisions.

Lungu described a number of programs that the country of Zambia and the University of Zambia are administering to improve food productivity. Zambia has been leading the effort to adopt conservation farming, in which microbasins are dug using a hand hoe and seeds are placed so they get water when it collects in the basins. These microbasins double or triple corn yields. The university is involved in breeding and mutagenesis efforts to produce stress tolerant crops and corn and sweet sorghum for biofuels and legumes. The university also is doing research on irrigating with river water polluted by mines. In general Zambia's water is extremely polluted, so controls need to be developed to prevent industrial and agriculture pollution.

At a continental level, Lungu continued, Africa is trying to promote regional integration. African countries have developed the New Partnership for Development, which includes the Comprehensive Agriculture Development Program. One of the key pillars of this effort is to develop a framework for sustainable land and water management. The University of Zambia is the lead institution for this pillar. The Country Round Table also was established to diagnose problems and design programs to address them.

"You (developed nations) have exploited your water. You have utilized it for development, but Africa has not developed, and we are hungry," Lungu said. "There are a lot of problems and people are living on less than a dollar a day, and yet the water is there." Zambia needs to exploit the water available to provide food security and reduce poverty but also avoid the mistakes developed nations have made, she said.

Ramesh Kanwar: The Role of Science and Technology in Water for Food

Ramesh Kanwar, an agricultural and biosystems engineer, has applied his expertise in sustainable irrigation and drainage systems, natural resources and water quality engineering extensively around the world as a consultant for the Food and Agriculture Organization of the United Nations, the World Bank, NATO and other international organizations.

Ramesh Kanwar

Kanwar began by stating how impressed he was to see University of Nebraska President James B. Milliken, Chancellor Harvey Perlman, several vice chancellors, other administrators and faculty in the audience throughout the forum. "I have been in academe for 32 years, and I have never seen a president and chancellor sitting all morning in the same session. It shows your commitment; it shows you are very serious."

Can we double food production? Kanwar launched his talk with the forecasts that indicate by the year 2030 humans must produce 50 percent more food to feed the world's population. By 2050, humans must produce 100 percent more food. The big question for Nebraska remains: By 2050, can Nebraska produce twice the amount of food it produces today with half as much water? Assuming the amount of water used for agriculture stays the same as today, Nebraska's productivity per drop of water consumed will have to double. To achieve that goal, scientists will have to develop more efficient plants that use less water and recycle nutrients more effectively, and develop better irrigation systems. This is where science and technology must play a major role, he said.

Water availability and quality. Food production has multiplied many times in areas where intensive agriculture has been developed. As a result, in countries such as India, groundwater tables have dropped 800 feet in the past 30 years. Water tables also are declining in Nebraska. "Are we going to develop the landscape so the land can absorb more water and, by increasing water infiltration, start recharging our depleted groundwater systems?" Kanwar asked. He believes increasing recharge would address some of the ecological issues the planet faces.

Kanwar also addressed the need to address water quality issues. Daily actions affect water quality. If this isn't addressed soon, by 2050 more people will die because of poor water quality than lack of food.

Global warming. Another major challenge is global warming. Some forecasts predict that all glaciers will melt away in the next 30 to 50 years. If that holds true, the rivers fed by these glaciers also will disappear. Sea water could rise 20 to 30 feet, forcing the 2 billion people whose livelihoods depend on rivers such as the Ganges in India, the Hingol in Pakistan, the Yellow in China, and similar river basins in south China and central and southeast Asia to flee. With these tremendous landscape changes, the people living along these rivers would not be able to support themselves.

Integrated training at universities. Kanwar ended by arguing that universities must change curricula to fit the water science and water engineering needs of the future. Courses in water policy, water marketing or water law must be offered to engineers and

scientists so they can become an integral part of the dialogue. For these reasons, Kanwar said, he hopes the proposed Global Water for Food Institute will provide a knowledge base for global water issues and become a leading voice for the U.S.

Vincent Vadez: Increasing Rainfed Agricultural Production

Vincent Vadez is a crop physiologist at the International Crop Research Institute for the Semi-arid Tropics. His specialty is the impact of abiotic stresses such as drought and salinity on plants.

ICRISAT is one of the 15 centers of the Consultative Group on International Agricultural Research, which works to improve crops and commodities in the developing world. ICRISAT approaches the issue of water limitation with an Integrated Genetic and Natural Resource Management paradigm, looking at the optimum combination of genetics and management to maximize the return in grains or dollars from a limited amount of water. "We don't just look at the crop itself, but in partnership with other CGIAR centers, we look at the entire crop-livestock system," Vadez said.

ICRISAT's mission is to improve the livelihood of people living in the semi-arid tropics, where many people live on far less than one or two dollars a day. The mandate of ICRISAT is to improve five dryland crops that are well adapted to limited water conditions: sorghum, pearl millet, great northern beans, chickpeas and black-eyed peas.

Vincent Vadez

Blue water and green water. ICRISAT works with blue water, which is water from streams and groundwater used for irrigation, and green water, the water in the soil profile. With regard to blue water, ICRISAT has an active community watershed program to maximize water capture and to improve the small proportion (only 35 to 45 percent) of rainwater eventually used by crops. ICRISAT promotes water harvesting technologies and the use of percolation tanks to promote groundwater recharge. ICRISAT also collaborates with institutions that specialize in groundwater resources by advising on water-efficient crop rotations and finding the best crop options to optimize the use of groundwater resources.

"What ICRISAT can bring in a water institute is a more global dimension where we need to look very carefully at green water," Vadez said. Eighty percent of crop production worldwide is rainfed – it depends on green water. ICRISAT provides advice on the most preferable crop rotations, such as promoting dryland crops like sorghum and pearl millet, which are well adapted to water-limited conditions, as opposed to water-intensive crops such as rice, which continues to be favored.

ICRISAT also works on magnifying the recharge of the soil profile, reducing the volume of water evaporated from the soil and increasing the volume of water in the soil that crops can access. Among the techniques promoted by ICRISAT are land form treatments such as broad bed furrow, landscape management using half-moons, and in-situ soil conservation through no-till and crop residue mulching.


Ron Yoder

ICRISAT's major work is drought avoidance. One program uses biotechnology to identify and harness superior rooting traits to capture water. ICRISAT has a large facility that allows precise in-vivo assessment of root-related traits and the development of new approaches to assessing the capacity of plants to exploit the water in the soil profile. It also tests transgenics and has large germplasm collections with a wealth of variations that can be exploited for genetic improvement. ICRISAT has combined these approaches to find crops that are better able to capture moisture from the soil profile and produce more yields per unit of water consumed. Vadez said he agreed with Richard Allen's comment that researchers shouldn't be talking about water efficiency but about increasing the amount of crop produced per unit of water consumed.

Because soil fertility also affects yield, ICRISAT is working on optimizing soil fertility using micro-dosing techniques, seed priming and seed pelleting, which allow the delivery of an affordable amount of nutrient to the seedling. Vadez emphasized a key issue is ensuring that farmers have access to affordable fertilizers.

The real issue is resilience. Resilience – learning how to produce food while accounting for crop failures – is the real issue, Vadez said. In other words, a certain amount of yield potential is sacrificed to ensure there is some yield every year.

In summary, Vadez said promoting dryland farming is one way to increase productivity. Eighty percent of the world's food production is grown under rainfed conditions. To produce enough food to match the growth in population by 2050, researchers will need to increase the productivity of dryland farming.

Ron Yoder: Business as Usual is No Longer Enough

Ron Yoder has worked in agricultural water management for more than 30 years and has extensive international research experience, including stints in Brazil, Zambia and China.

Yoder began his presentation by reiterating Simi Sadaf Kamal's statement: "If we want to get to where we need to be – producing more food with less water – we cannot continue with business as usual."

Yoder noted that technology has advanced significantly to squeeze the last bit of benefit out of a unit of water. However, in most cases the technology is not being used because (1) the knowledge transfer does not reach those people who need it most; (2) the cost of technology is not aligned with what the end users can afford; and (3) as Richard Allen pointed out, many don't understand the baseline hydrology and water budgets. When examining the amount of production per unit of water used, whether a scientist considers just the plant, field, irrigation district, watershed, river basin or continent makes a difference, Yoder said.

Science and technology panel discussion

Science and technology provide many answers for making better use of scarce water resources, Yoder said, but to realize their true value, solutions must be integrated with sociological, policy and educational issues. If any one of these three factors is left out, it is not possible to maximize the benefit of each unit of water.

Questions and Answers

Moderator Sheri Fritz: *Given all the challenges, what do you see as the key scientific and technological issues that need to be addressed, and which of these issues do you think the Global Water for Food Institute at the University of Nebraska would be, if not uniquely equipped to address, at least in a good position to address?*

Vincent Vadez emphasized the need to focus on green water and on dryland or rainfed farming because there is no other option in many parts of the world. Ron Yoder said to maximize water usage, researchers need real-time decision support systems that provide inexpensive real-time information and data to help them make decisions. Ramesh Kanwar described a project he is working on in India that is providing a wireless technology network so farmers in villages can access accurate weather forecasting so they don't over-irrigate and waste water. Judith C.N. Lungu thought the institute should encourage research on the impacts of stress factors on crops to spur development of new crop varieties that optimize the use of available water and better meet the challenges of increased drought. Brian Larkins reiterated that the institute needs to bring together all information about agricultural and municipal issues, and new crop improvement technologies that is scattered across many organizations. A single, easily accessible Web site that contains all water-related information would be a major contribution, he said.

Fritz: *Can you identify any technology gaps, areas where we do not have the information we need to make progress on producing more food with less water?*

Kanwar said he believes there is still much room for improving irrigation systems. When he has visitors from other countries who want to learn about irrigation, he always brings them to Nebraska. He added that scientists should continue developing new varieties of crops that are more drought tolerant and require less water, fewer nutrients and less soil concentration. Corn doesn't have to be six to eight feet tall, he said.

Vadez emphasized the importance of developing genetic labeling, the need for more testing of new varieties to understand the impacts of using these plants, and the importance of being honest with the public. More research on dryland crops is needed, he said, and experts should encourage the use of existing drought-adapted dryland crops.

Yoder said it would be useful to know at the beginning of the season how much water will be available for crops and when to irrigate to maximize the benefit from the water available.

Larkins said the potential for learning how plants deal with drought has never been better. Researchers have learned more about the physiology of plants in the last 10 years than in the previous hundred years. The tools are there and interest in this area is great, he said. However, he cautioned, a major challenge for the U.S. is the shortage of plant breeders. It is difficult to find students who are not only knowledgeable in basic plant breeding techniques but also have enough understanding of molecular genetics and genetic markers to integrate these skills in a breeding program, Larkins said.

Mark Gustafson, Coordinator of Rural Economic Development, University of Nebraska Rural Initiative: *Given all the issues that need to be addressed, both social and technological, should the institute focus on culture, laws and policies, or would it be better to form partnerships with people who already have capacity to do those things?*

> *"Resilience – learning how to produce food while accounting for crop failures – is the real issue."*

Judith C.N. Lungu said a global institute must engage the Third World countries and bring them to a higher level of food production so citizens can feed themselves. "Instead of choosing only those countries that already have the capacity to partner with you, I believe you need to partner with developing countries, allow developing countries to have input into the direction you adopt so they can benefit from your efforts," she said.

Kanwar had a different viewpoint. If Nebraska is making the investment, he said, the institute must think globally but act locally to solve the problems that the state of Nebraska faces. The question of what new knowledge needs to be created must be decided within the university system. However, a global perspective also is key because the U.S. is no longer the only leader in this field. The Global Water for Food Institute could provide a new level of leadership by creating partnerships with industry and foundations that can fund its work. The core mission of educational institutions like the University of Nebraska also includes training the future workforce. Hopefully, there will be endowed fellowships to train people to help the countries that cannot provide such training themselves, he said.

Prem Paul, Vice Chancellor for Research and Economic Development, University of Nebraska–Lincoln: *We understand this is one of our biggest challenges, but if we look at the investments we're making in research, they are not sufficient. My understanding is that there is more dialogue in Washington, D.C., to invest more resources. The National Science Foundation has made this one of the major topics as its funding increases. The question is, from a science perspective, what is missing? What are the major gaps in science that need to be addressed through research?*

Vadez answered that the integration of knowledge from different disciplines is lacking. He believes the question of whether to focus on Nebraska issues or global issues is not relevant as long as the institute links the pieces together in a partnership mode, bridges the gaps between disciplines and harnesses the wider framework of genetic and natural resource management to deal with drought situations. The pieces are there; it is a matter of tying them together, he said.

In contrast, Larkins said researchers know very little about how crop drought tolerance works. It is a very complex trait that varies from one plant to the next. "Maize and sorghum are very closely related, and you would think we had some idea of why sorghum is drought tolerant and maize is not, but we don't," Larkins said. He added there also is a limit to how far breeders can push these crops to make them drought tolerant. Cactus plants in Arizona are wonderfully adapted to grow with hardly any water at all. The problem is they don't grow very fast, so people would starve if they had to eat only cactus. "Considering the time frame we have to solve this problem, which is the next 20 years, and considering how long it takes to develop a new crop variety, especially if it's a transgenic variety, which is going to require six or seven years of testing before we can make it available, we're really behind the eight-ball," Larkins said. Improving the food value of existing drought resistant crops, such as sorghum, so they could become primary food sources would be ideal, but there is much to learn about how to do this.

From left: Ramesh Kanwar, Judith C.N. Lungu, Brian Larkins, Vincent Vadez, Ron Yoder

Kanwar responded that identifying the knowledge gaps is key, which vary greatly depending on local factors such as the cost of energy and water, water policies and subsidies. However, Kanwar continued, the overall focus should remain on solving bigger societal issues. Food scarcity is going to be a challenge by 2050. Some populations will not have enough to eat; others will have plenty. How will societies share? The population is not going to double by 2050, but food production will. Why? The simple reason is that in countries with rapidly growing economies like China, which now consumes only 20 to 30 percent of the amount of food Americans consume, people want the same quality and amount of food available in the U.S. This is a major contributor to the imbalance of food among countries.

In closing, Fritz said that some fundamental scientific knowledge gaps need to be addressed in an integrated fashion. To date, this integration of knowledge across multiple disciplines has been missing. Finally, the institute needs to look at the big picture and decide which global issues and challenges Nebraska has the expertise and talent to address. Efforts should focus on these areas.