Special Issue, Part 2
March/April 2015

RESOURCE

engineering and technology for a sustainable world

Feed the World in 2050

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Engaging Challenges

This issue of *Resource* is the final installment of a two-part special focus: **Feed the World in 2050**. In the November/December 2014 magazine, Society members—John Schueller, Nicolas Kiggundu, Otto Doering, Bruce Dale—and aligned colleagues shared their thoughts on how we need to engage to feed a projected 9+ billion global population.

The critical thinking continues on these pages. ASABE members underscore that the challenge involves a globally collaborative and interdisciplinary endeavor, where ag and bio engineers will be engaged as game changers. Linus Opara in South Africa, Chandra Madramootoo in Canada, Dick Godwin and Simon Blackmore in the U.K., Theodor Friedrich in Cuba, Markus Demmel in Germany, Josse De Baerdemaeker in Belgium, and others from Australia, Brazil, Haiti, Switzerland, Taiwan, and the U.S.—all weigh in. Wherever I travel as your president, the greatest global challenge ever faced is constantly set before me. I am excited to see the dialogue continue and thank Tony Grift for his gracious overseeing as guest editor.

In light of this challenge and others, **one of the most important things we can do is inspire and engage the next generation of engineers.** As the organizational co-chair of **Engineers Week 2015**, ASABE has had many responsibilities and diverse opportunities to serve during activities associated with this premier event for promoting engineering. Our members did an outstanding job filling needs for *Future City* judging at the regional and national levels. They generously committed to supporting *Family Day* and *Introduce a Girl to Engineering Day*. We can be proud of the exposure ASABE received, but most of all, **we applaud Society members who engaged in E-week to sustain and grow a dynamic engineering profession through outreach, education, celebration, and volunteerism.** Keep up the good work!

When this *Resource* hits your desk (or tablet or phone), ASABE members and staff will be in high gear planning for the Annual International Meeting in New Orleans. The 2015 AIM will bring many opportunities for members to engage with each other—sharing technical progress across our profession, learning more about enhancements of our impact on globally relevant concerns, and becoming acquainted with improvements of Society governance. I hope you are making plans now to attend.

In closing, I want to encourage ASABE members about to take our inaugural spring Agricultural and Biological Engineering PE exam. Here's to your success! Thanks to members of the PAKS committee, EOPD-414, and the PEI for engaging in resolving the content issues for the exam, writing and improving exam questions, and providing study guides and review sessions for prospective takers. My hope is that the new exam specifications and new time slot in the spring will help us stabilize our exam for many years to come.

Terry A. Howell Jr., P.E.
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events calendar

ASABE CONFERENCES AND INTERNATIONAL MEETINGS

To receive more information about ASABE conferences and meetings, call ASABE at (800) 371-2723 or e-mail mtgs@asabe.org.

2015

May 3-5	**ASABE 1st Climate Change Symposium—Adaptation and Mitigation.** Chicago, Illinois, USA.
July 26-29	**ASABE Annual International Meeting.** New Orleans, Louisiana, USA.
Nov. 10-12	**Irrigation Symposium.** Long Beach, California, USA.

2016

July 17-20	**ASABE Annual International Meeting.** Orlando, Florida, USA.

ASABE ENDORSED EVENTS

2015

May 31-June 5	**2015 18th International Soil Conservation Organization (ISCO).** El Paso, Texas, USA.
July 5-8	**CSBE Conference & Annual General Meeting.** Edmonton, Alberta, Canada.
Oct. 23-26	**2015 International Symposium on Animal Environment and Welfare.** Rongchang, China

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Feed the World in 2050
Does Hans Stand a Chance?

The November/December 2014 issue of *Resource*, "Feed the World in 2050—Part I" was intriguing. I thought I knew what poverty meant until I read Robert Zeigler's article. I was thrilled to see Ken Quinn's tribute to a true American hero—Norm Borlaug. And I was honored that World Food Prize winner Mary Dell Chilton contributed to the first issue of this two-part series. This second issue has a variety of outstanding contributors as well, among them Deputy U.S.Secretary of Agriculture Krysta Harden. We are in great debt to our contributors.

In 2014, NASA funded a study to develop the Human and Nature Dynamics (HANDY) model, which claims that "the process of rise-and-collapse [of societies] is actually a recurrent cycle found throughout history." It turns out that "advanced, sophisticated, complex, and creative civilizations can be both fragile and impermanent." The HANDY model asserts that resources, as they run out, become more expensive (as we are well aware), which devastates the poor but merely annoys the rich, thereby dividing the haves and the have-nots (nothing new there either). Furthermore—"Collapse can be avoided and population can reach equilibrium if the per capita rate of depletion of nature is reduced to a sustainable level, and if resources are distributed in a reasonably equitable fashion"—if only the model would tell us how to do that.

Tony Grift, Guest Editor
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This is where I thank Otto Doering for his insights in Part 1 on "A Truly Wicked Problem," meaning a problem that is not amenable to solution by scientific methods. Given that we have volumes of data, powerful computers, elaborate software models, and satellites beaming down more data all the time, what renders any problem truly wicked? I'm pretty sure it has to do with the way we evolved.

Humans, like every other land animal, evolved from fish. The next time you hiccup, remember that it's essentially an atavistic amphibian mechanism for controlling the motion of gills. Similarly, the human brain started with the brain stem, a primitive neural cord that guided the behavior of our reptilian ancestors. Not much thinking goes on there, as it mainly serves low-level functions such as breathing, swallowing, and sneezing. Later, the limbic system evolved, literally on top of the brain stem, giving us emotions such as lust, anger, fear, and jealousy. Subsequently, a large mammalian feature developed, called the neocortex, which is particularly large in *Homo sapiens*—the "wise man" (let's call him Hans). We like to think that our behavior is mainly controlled by our three pounds of neocortex, but that's true only when we're not starving or freezing, or being chased by a bear, or confronting a burglar.

With the neocortex, cultural evolution began. We developed feelings of connectedness and community (watch my kid while I go gather some tubers), and soon we had learning, language, marriage, lawyers, economists, politicians, and armies. Now in 2015, we must ask our twittering Hans, together with his seven billion *H. sapiens* friends, to solve the problem of feeding themselves in 2050. What is the probability of Hans succeeding?

Otto Doering is quite right to imply that the problem of feeding nine billion people is tangled up with perceived values, biases, culture, and politics, rendering it impossible to solve with traditional scientific methods. Does that mean we should just let the future happen?

That seems to be exactly what we're doing. We may have a three-pound neocortex, but our deeply rooted limbic system makes us bigoted, capricious, irrational, petty, and sometimes just stupid. Europeans started two world wars that killed 80 million people and left entire cities in ruins. Yet historians are still trying to figure out why World War I happened, and WWI was the main motivation behind Hitler's WWII. On this side of the pond, scientists like me still have to be careful with the word "evolution" because it might offend someone. Recently, Australia imposed a CO_2 tax that actually reduced emissions, but Prime Minister Tony Abbott repealed it. In addition, Maurice Newman, chair of Abbott's business advisory council, claimed that Australia is ill prepared for global cooling! Perhaps Ronald Reagan was right when he said: "The nine scariest words in the English language are: I'm from the government and I'm here to help." Unfortunately, government doesn't have a monopoly on ignorance.

Yes, we can feed the world in 2050 by doing more of the same, but in doing so we will destroy any chance of long-term sustainability. We will see a gradual but persistent increase in food prices due to depletion of resources and declining crop yields, and the poor will slowly become poorer, to the point of widespread famine. Saying that we would leave Earth a mess for future generations would be a misnomer; we would leave her in a nearly ruined condition. We will have exhausted all fossil fuels, polluted our soils with nitrogen sucked from the sky, raised atmospheric CO_2 to over 500 ppm (it increased from about 300 to 400 ppm in the first half of the Age of Oil), raised sea levels enough to drown coastal ecosystems, and depleted the aquifers.

A few centuries from now, after a long slow decline punctuated by sudden shifts and outbreaks of violence, we will reach equilibrium of probably one billion people. Those survivors will look back at the 21st century the way we look at the Roman Empire. "What on earth happened?" they will ask. What happened is that *Homo myopicus* could not rise above its limbic brain; our doom is written in our DNA. Eventually, future archeologists will uncover a CD by R.E.M. with the song "It's the end of the world as we know it (And I feel fine)." Then maybe they'll understand.

Top photo courtesy of NASA GSFC.

New Farmers are Key to Feeding the World in 2050

Krysta Harden

From a young age, I knew that in order to feed the world, we needed people who love the land to take care of it. I grew up on a peanut farm in southwest Georgia, where I learned about the value of hard work and dedication to the land. From working with the soybean industry to being named CEO of the National Association of Conservation Districts and now in my role as USDA's deputy secretary, I have dedicated my career to my twin passions: agriculture and conservation.

Our nation's farmers and ranchers have always cared deeply about the land, but farming as a profession has evolved tremendously over the past 50 years. Technology and innovation have paved the path for a successful agricultural sector, but more work remains. USDA continues to support all farmers and ranchers by helping them grow their businesses, promoting a strong rural economy and fostering economic growth worldwide. But at the end of the day, the most critical question of all becomes "Who will farm next?"

As deputy secretary, I have made it my mission to give those interested in working the land any and all opportunities to do so. But in order to feed nine billion people by 2050, we must secure the next generation of farmers and ranchers and give them the tools they need to succeed.

For example, new farmers often cite access to land and capital as their biggest barriers, so USDA has created a one-stop shop for all new farmer and rancher resources: www.usda.gov/newfarmers. This website is aimed at providing those who are just getting started with a breakdown of USDA programs and new farmer stories that showcase the varying opportunities that exist on the farm or ranch.

The face of agriculture is more diverse than ever before, and our programs and policies must reflect this change. We are seeing an increasing number of women, veterans, minorities, and immigrants choosing agriculture as their profession. From the field to research labs to board rooms across the country, there are more opportunities in agriculture than ever before.

It has been estimated that it will take as much innovation in agriculture in the next 40 years as in the preceding 10,000 years to be able to feed a growing population. USDA researchers are hard at work in locations across the country developing new ideas and making data available to scientists all over the world in the hopes of expanding our understanding and increasing our efficiency in food production.

This past summer, I saw firsthand how the Feed Enhancement for Ethiopian Development (FEED) project, an activity supported by USDA's Food for Progress program, has boosted milk production through better feeding practices and farm management in Africa. Thanks to the FEED project, a young woman is running a largely self-sustaining farm that is employing members of the local community.

USDA Deputy Secretary Krysta Harden with dairy farm owner Yetemwork Tilahun on Tilahun's farm near the city of Mojo, about 50 miles south of Addis Ababa, Ethiopia, in August 2014.

A thriving agricultural economy plays a crucial role in food security. But as we take on the challenges of feeding a growing global population, it is equally critical that we deal with the impacts of a changing climate. We have seen firsthand the impact of increasingly severe droughts, floods, extreme temperatures, and other dramatic weather patterns. As the impacts of climate change become more prevalent, farmers and ranchers around the world will need new tools and techniques to protect their bottom line and ensure global food security. That is why in September, the United States, along with several of its partner countries at the United Nations, launched the Global Alliance for Climate Smart Agriculture, an effort aimed at charting a more sustainable path to worldwide food security.

In the United States, farmers and ranchers are working to mitigate the impacts of climate change by employing cutting-edge conservation practices on their operations. The 2014 Farm Bill provides more conservation funding than ever before. Going beyond the traditional scope of government support, initiatives like the Regional Conservation Partnership Program are bringing new partners to the table when it comes to protecting our most precious natural resource: the land.

Our farmers and ranchers are incredible environmental stewards, and we must continue this legacy for generations to come. The future of agriculture is bright, but it is up to all of us to recruit a new and diverse set of farmers and ranchers in order to feed our growing world population.

Krysta Harden was sworn in as Deputy Secretary of USDA on August 12, 2013, after unanimous U.S. Senate confirmation. She helps lead the department, focusing on strengthening the American agricultural economy and revitalizing rural communities.

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Mid-page photo courtesy of USDA.

Establishing a World Hunger Abatement Task (WHAT) to Build Intelligent Food Systems (IFS)

Managing the WHAT-IFS

K. C. Ting, P.E., and Kathryn C. Partlow

Creating a world with no hunger and with abundant energy, a healthy environment, and resilient families and communities is the grand challenge we face. Hunger is a solvable problem, and it is the root cause of many multi-faceted, multi-scale problems. Great strides have been made in hunger abatement. We believe the next step is to create a comprehensive, worldwide approach, called the world hunger abatement task (WHAT), that will build on current knowledge and integrate that knowledge in order to maximize its benefit. This integration of knowledge can be achieved through the development of intelligent food systems (IFS) that use a science-based approach to coordinate food production, processing, and distribution with sustainability and resource management.

The Problem

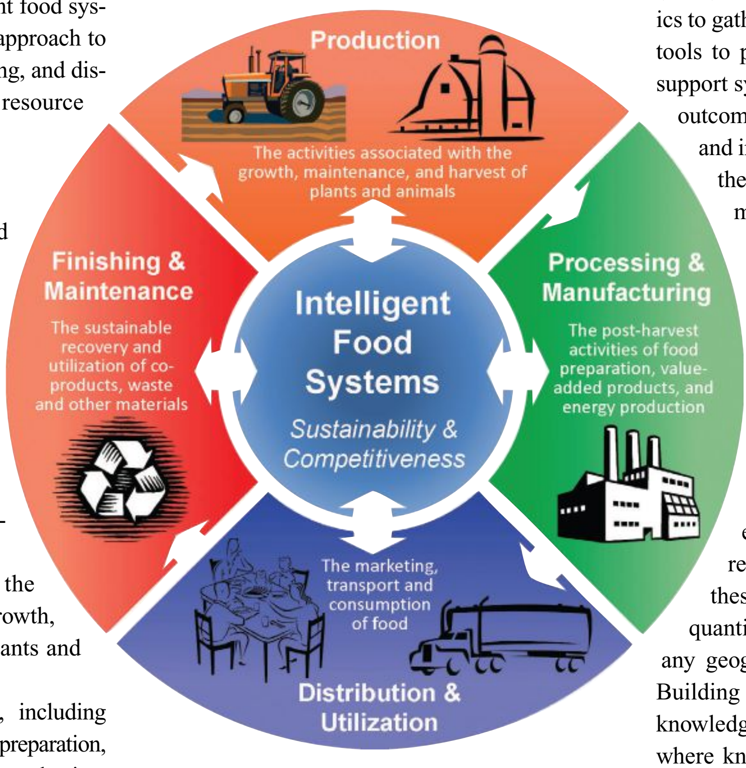
The complexity of our food systems is a major obstacle to conquering hunger. Food systems are locally operated but globally connected; they encompass a broad range of physical, chemical, biological, and sociological activities; and they are influenced by time-varying, site-specific, and interdependent variables. The components of food systems include:

- Production, which includes the activities associated with the growth, maintenance, and harvest of plants and animals.
- Processing and manufacturing, including post-harvest activities of food preparation, value-added products, and energy production.
- Distribution and utilization, which includes transportation, marketing, and consumption.
- Finishing and maintenance, including the sustainable recovery and utilization of co-products, waste, and other materials.

Given our limited resources, each component must be both environmentally and economically sustainable for successful adaptation. Impressive advances have resulted from research in specific areas (i.e., making one component work better). However, a major effort is needed to make all the components work together by understanding their interconnections, investigating the tradeoffs, and providing decision support for optimization at the system level.

The Solution

An information system consisting of effective content and efficient delivery will empower farmers, manufacturers, consumers, and policy makers in their decision making. Fortunately, a variety of information technologies are already available that can empower IFS planning, design, management, and operation.



The IFS approach considers the entire scope of the food system at the local, regional, and global scale.

In order to build an IFS, we propose the development of a concurrent analysis platform (CAP). The purpose of a CAP is to integrate information and knowledge related to the system under study from various sources, perform systems analysis, evaluate systems-level performance, and deliver the results of the analysis based on the most current information. The four key elements of a CAP are:

- System scope and objectives, with varying degrees of criticality.
- Resources (including human, information, physical, and financial, among others), with varying levels of implementation readiness.
- Mission scenarios describing site-specific, initial, and boundary conditions.
- An action plan providing support for decision making.

Implementing a CAP requires the involvement of stakeholders, like you, to build three key information, knowledge, and wisdom (IKW) empowered elements: domain informatics to gather information, modeling and analysis tools to process the information, and decision support systems to present the information. The outcome is a comprehensive systems analysis and integrated cyber environment that helps the CAP users (including researchers, managers, farmers, policy makers, etc.) identify technological, social, economic, and policy barriers, evaluate novel solutions, and provide region-specific recommendations.

The proposed solutions will be evaluated using multiple criteria, such as quality of life and income improvement, costs, resource requirements, environmental impact, economic competitiveness, and regional sustainability. Tradeoffs among these performance measures will also be quantified. This framework is applicable to any geographic region and any food system. Building an IFS will allow us to consider all the knowledge currently available, identify areas where knowledge is lacking, adapt the system as technology evolves, use real outcomes to create better solutions, and ultimately feed the world in 2050.

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Top photo by Scott Bauer, courtesy of USDA-ARS. Mid-page illustration by the authors.

To Feed the World, We Must Save the Harvest

Umezuruike Linus Opara

We need to save what we already grow.

I have been involved in agriculture all my life, from subsistence farming with my parents in our rural village in eastern Nigeria to an international academic career in Africa, New Zealand, Asia, and the Middle East. As a child, I began working on our family farm as soon as my hands were strong enough. Because we ate mostly what we grew, I learned what it means to produce a crop and save the harvest.

The global food insecurity that we face today is far more complex than the food insecurity that I experienced as a child. In addition to wars and nutritional deficiencies, the global food system is confronted by factors that limit our capacity to produce food sustainably, such as climate change. Additional factors are the rapidly growing urban population, especially in sub-Saharan Africa and Southeast Asia; the rapid decline of finite natural resources, such as arable land, fresh water, and fossil energy; and the negative impacts on our ecosystem.

First we need to engage

These challenges demand urgent and sustained action from our political leadership. But they also call for agricultural and biological engineers to **engage**, as ASABE President Terry Howell put it recently, with "colleagues and thought leaders from around the world." **One way that we can engage is by leading the effort to save the harvest by reducing postharvest losses.** More than a century ago, confronted with the looming catastrophe of insufficient food production, our forebears responded by expanding agricultural engineering education and research, which produced radical new technologies. As recognized by our peers in other professions, we led the way in harnessing the tremendous power of mechanization, transforming agriculture into an engine of economic development.

Since then, the global food system has been neglected, and it's time for agricultural and biological engineers to take the lead again. Now we need to save what we already grow. Over 30% of all food (equivalent to 1.3 billion tonnes) never becomes nutrition because it is lost during handling and processing, or discarded during preparation and consumption. In the mid-1970s, a seminal report by the U.S. National Academy of Sciences found that the average level of postharvest losses (~33%) was similar in both developing and developed countries. While most losses were closer to the farm in developing countries, losses were higher downstream, at the consumer level, in developed countries.

A more recent study by the FAO showed that the magnitude of losses has not changed. This report also showed that total food wastage was higher in developed countries than in developing countries. Losses of fresh produce were particularly high and can reach 40% depending on the value chain.

Saving what we already grow

We now know that intensive agriculture, which thwarted the Malthusian apocalypse, is a major contributor to climate change and environmental degradation. Most of the production increases of the past century were mainly due to increases in cultivated area, which often involved deforestation and resulted in loss of topsoil and biodiversity. And we know that agriculture is not an efficient converter of resource inputs. Some crops require more than four times as much fresh water as their unit weight at harvest. It is not surprising that agriculture accounts for up to 70% of total fresh water use in regions that depend on irrigation.

In addition, the rate of yield increase of major crops has continued to decline during the past century. In Europe, North America, and Asia, where high-yielding varieties of wheat, rice, and corn (in combination with other technologies) created the Green Revolution, yields have stagnated, implying a "yield ceiling." While developments in biotechnology have shown promise in breaking through the yield ceiling, they are not a panacea. Instead, saving what is already produced offers an immediate entry point for our strategy to feed the world in 2050. Reducing postharvest losses is a worthy goal, but losses can never be zero. Therefore, determining the critical levels of waste that warrant technological intervention is important, along with designing and disseminating cost-effective tools to reduce waste and identify the weak links in the value chain.

To enhance the capacity and competitiveness of the South African agricultural industry in particular and Africa in general, the South African Research Chair in Postharvest Technology was set up in 2009 at Stellenbosch University under the Research Chairs Initiative (SARChI) of the South African Department of Science and Technology and the National Research Foundation. Through private-public partnerships and continent-wide networks, SARChI Postharvest Technology has developed multi-disciplinary research in engineering and science, with students enrolled from various countries in Africa. Short-term training projects have also been implemented to improve postharvest management in African countries, including research internships for postgraduate students from around the world. In addition, the Chair has contributed to high-level panels and policy initiatives to improve postharvest technology at national, continental, and global levels. Through these kinds of practical, collaborative efforts, we can apply the unique skills of agricultural and biological engineers to reduce postharvest losses, save the harvest, and feed the world.

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Top photo by Keith Weller, courtesy of USDA-ARS.
Top inset photo © Sjankauskas | Dreamstime.

Increasing Productivity through Cooperative Conservation

Jim Moseley

In 1977, the soil in my Indiana community had been slowly degraded and could not perform at peak productivity. Yet our yields were increasing due to new technologies—better seeds, low-cost fertilizer relative to grain price, chemicals that cleaned the fields of pests. As a result, we hardly noticed the productivity decline. However, we had removed a significant amount of the "building blocks" of soil formation, what soil technicians called organic matter. That slow and subtle change, hardly perceptible from year to year, was beginning to limit crop performance.

We discovered this discouraging state of affairs when a new crop advisor arrived on the scene. He first helped us to see the problem, and then he led us to the tools and practices we needed to restore the natural quality of our land. Soon our productivity increased, due to new technology as well as the soil resource. This new concept became the mission for the whole community.

This is the learning process in farming communities. When improved soil management is combined with new technologies to yield improved crop performance, local farmers see the progress and become part of the effort. Wider participation leads to improvement in other areas of public interest—things like water quality and wildlife habitat. In our case, we created a network of over 100 operations in three counties, all working together to improve soil quality. Managing our farm operations and the watershed in which we all lived as systems—connecting yields, soil health, organic matter, water quality, and cropland resilience—was good for us as farmers and very good for the rest of society.

Cooperative conservation provides an excellent model for farmers and ranchers anywhere who are working to meet the long-term food, feed, fuel, and fiber needs of a growing population. The key is to have local leadership guiding all aspects of productivity, rather than just following the technology trail, as we did in the decades after WWII. In fact, farmers and ranchers who work the land are the only members of the food production system who can change the way we align productivity, profitability, and high-quality natural resource management. If we are going to feed 9 billion people in 2050, we must fully utilize the soil resource, as well as new technology as it emerges, to improve productivity.

AGree asks farmers and ranchers of all types to weigh in on the challenge. We also convene supply chain leaders, researchers, health experts, nutrition experts, international policy experts, and representatives from conservation and environmental organizations. Together, these thought leaders challenge each other to articulate collaborative means by which the food and agriculture system can meet the challenges of the 21st century. Our sensible solutions for making cooperative conservation a reality on a broader scale include:

- **Companies interested in sustainable sourcing should reward producers who are actively engaged in collaborative conservation.** Companies should recognize producers who actually demonstrate continuous, measurable sustainability improvements, rather than assigning one-size-fits-all checklists.
- **Agricultural groups should encourage local producers to spearhead cooperative conservation projects in their communities.** Agencies should provide training and professional development opportunities to give representatives and technical staff the skills needed to facilitate these projects.
- **Cooperative conservation requires time, experimentation, and adaptive management to get off the ground.** To encourage producers to engage in these initiatives, agencies should provide actively engaged producers with regulatory certainty through safe harbor agreements.
- **We need stronger public funding for agricultural research that supports productivity and environmental goals simultaneously.** Efforts like cooperative conservation can inspire applicable research and provide a ready audience for its implementation.
- **Government funding related to natural resource management should be shifted to support producer-led cooperative conservation projects.** The newly formed Regional Conservation Partnership Program, which funds landscape-scale efforts, is a good step in this direction.
- **Feeding the world while conserving natural resources must be a global effort.** International development initiatives should empower producers to increase their yields sustainably. Cross-cultural exchange of successful conservation and productivity strategies, including cooperative conservation, can benefit the global community.

AGree leaders gather to learn about land conservation on a farm in eastern Kansas.

These recommendations will guide AGree's advocacy for policy change and action. Our efforts will help advance on-the-ground projects that refine the cooperative conservation model and test the model in areas where farmers and ranchers face unique challenges. The lessons learned from these efforts will shape our advocacy for longer-term policy action to build the model across the U.S.

We have already seen cooperative conservation work in communities across the country and around the world. I've seen it succeed in my own area. Having tried the top-down approach for 30 years in U.S. farm policy, our goal is to invest in a different approach, and then hold it up to government and private sector leaders as a shining example of what works, finally making it a reality on a broader scale. With that accomplished, we can ensure healthy landscapes and food security for generations to come.

Jim Moseley is Co-chair of AGree, former Deputy Secretary of the USDA, and owner of a farm focused on grain and vegetable production; www.foodandagpolicy.org.

Top photo by Scott Bauer, courtesy of USDA-ARS.
Bottom photo courtesy of AGree.

The Miracle of Double-Cropping in Tropical Agriculture

Marcelo Duarte Monteiro, Peter Goldsmith, and Otávio Celidonio

Until the early 1970s, Brazil was a large importer of food. Now this country has the largest agricultural trade surplus in the world. According to the FAO, agricultural production in Brazil has grown by more than 500% in the last 50 years, increasing from 2.9% of world output to 10.1%. The interesting thing is that this agricultural revolution in Brazil can become even greater due to new production technologies, as well as the large areas of potential agricultural land that are currently underused as low-yield pastures.

According to CONAB, Brazil's natural resource agency, in 1976 the center-west region of the country, known for the vast tropical savanna called the *cerrado*, was responsible for 12% of national grain output, while the southern region, with a temperate climate, was responsible for 59%. The agricultural map of Brazil began to change in the 1970s with the use of technologies such as lime application for acid correction of the *cerrado* soils. These new technologies and adapted seed allowed farming to spread into the center-west, which became Brazil's new farming frontier, currently producing almost 40% of Brazil's total grain output.

While the first crop to be planted in the *cerrado* was rice, real agricultural development occurred with the improvement and consolidation of soybean farming. The expansion of soybeans coincided with a worldwide increase in the demand for protein without the use of expensive and energy-intensive nitrogen fertilizers. Soybeans became the main source of protein for animal feed around the world. Currently, Brazil is the world's second largest soybean producer and should become the largest in the next few years due to the large areas of pastureland that are still available for cultivation.

Brazil is the world's fifth largest country in terms of territory, with a total area of 851 million ha, of which 534 million ha are protected, 60 million ha are used for agriculture, and 198 million ha are used for pasture. Brazil could double its agricultural area without affecting the conservation of forest areas by converting just a third of its pasturelands. This is why the FAO and the World Bank consider Brazil to have the largest potential for agricultural expansion in the world.

As well as horizontal growth, Brazilian agriculture has also increased its yields per hectare. An important innovation is taking place in the *cerrado* region: a double-cropping system called *safrinha*. Because of the seven to eight months of rain each year, with stable temperatures all year round, successive crops can be grown in a single year. The *safrinha* system involves planting corn as a second crop soon after the soybean harvest in the months of January to March. The corn then is harvested from June to August of the same year. Both crops are produced without irrigation. Mato Grosso, which lies between -10° and -15° south latitude, has become Brazil's leading soybean producing state. Meanwhile, the production of second-crop corn in Mato Grosso has grown in the last ten years and is now 63% as large as the soybean crop. The increase in second-crop corn production has been greater than 12% a year, and more than 335% in the last ten years. In 2012, second-crop corn production surpassed first-crop corn.

Double-cropping of soybeans and corn has placed Brazil in a position of importance in terms of protein and oil yields per hectare. According to an analysis by the University of Illinois, the *safrinha* system out-yields temperate zones in energy, protein, and oil production per hectare. The only exception is the energy yield per hectare of the double-cropping system, which is 24% less in Brazil than in Illinois due to Brazil's lower corn yields.

At 64% of Midwest U.S. yields, corn yields in the tropics have not reached their full potential. Over the last few decades, genetic improvements in corn have focused mainly on production in temperate zones, which have long days and short, cool nights. However, new research efforts for tropical corn have already generated good results. Corn productivity in Mato Grosso has been growing by 5% a year and while the current yield is more than 6 metric tons per hectare, some producers are doubling this in certain areas.

According to the same University of Illinois study, the world's tropical agricultural regions (between 15° north and -15° south latitudes) produce a combined total of 85 million ha of soybeans and corn annually. **If the double-cropping system is replicated successfully in other countries in Latin America, Africa, and Asia, without increasing the planted area, these low-latitude countries could meet 47% of the growing energy demand, 67% of the protein demand, and 70% of the additional vegetable oil demand by 2050.**

Of the more than 9 billion people who will inhabit the Earth in 2050, about 53% will live in tropical countries. As a result, the importance of these regions for agricultural production will be even greater. Brazil and the other 28 tropical countries will certainly make large contributions to the increase in food production by 2050. The question is if all these countries will be able to adapt this promising production model to their own particular situations.

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Top photos by Doug Wilson and Peggy Greb, courtesy of USDA-ARS.

Feed the World in 2050...and *Nourish* it, too

Maureen Mecozzi and Dyno Keatinge

If basic sustenance was the goal of agriculture in the past, improved nutrition must be an equivalent priority for the future. The World Vegetable Center seeks to overcome malnutrition and poverty and facilitate good health in the rural and urban poor by increasing the production, quality, consumption, and profitability of nutritious vegetables. We promote good agricultural practices, work with partners to create opportunities for employment, and emphasize effective postharvest value addition and marketing mechanisms. The World Vegetable Center is the only not-for-profit international agricultural research center that has a worldwide and exclusive mandate for vegetable research and development.

Founded in 1971 as the Asian Vegetable Research and Development Center (AVRDC), the Center's global operations now cover sub-Saharan Africa, East and Southeast Asia, South Asia, Central and West Asia and North Africa, Oceania, and Central America. Agronomic practices that conserve water and protect crops and effective integrated pest management packages are disseminated to farmers in the developing world. To reduce food losses, the Center researches methods to maintain postharvest quality all along the vegetable value chain.

Vegetable species with tolerance to flooding, drought, heat, and other environmental stresses, and with the ability to maintain yields in more marginal environments, are identified to serve as sources for public and private vegetable breeding programs. The Center also seeks out suitable germplasm capable of thriving under conditions of climatic uncertainty.

AVRDC plant breeders focus on open- and self-pollinated vegetable crops. We select global and traditional vegetables with enhanced nutrient density and production characteristics appropriate for small-scale producers. The Center encourages diversity in vegetable cropping to reduce farmers' risk and increase their resilience. Furthermore, we promote wide diversity in diets—an important component of a healthy life.

The AVRDC Genebank is the world's premier collection of tropical and subtropical vegetable genetic resources in the public domain; its seed, knowledge, and information are accessible to all. The Center places vegetable germplasm with new, desirable traits such as resistance to viruses, fungal and bacterial diseases, and insects in the public domain under the auspices of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), thus ensuring access for both the public and private sectors.

The Center produces seed kits of well-adapted, nutritious vegetables appropriate for households, schools, prisons, and hospital gardens for people to grow their own crops. **Having access to own-grown vegetables throughout the year is especially beneficial for women, children, and the elderly, who are most in need of the nutrients that vegetables supply.** The Center's home garden kits kick-start entrepreneurship on a small scale, and they can be the first step for families to grow themselves out of poverty. The kits are also provided to disaster victims through relief agencies. With good-quality seed, victims of natural disasters can grow vegetables on small areas of land and thus quickly add nutrients to their diet.

Over the past 40 years, AVRDC has trained many thousands of NARES, NGO, and private sector personnel, and we will continue this training in the future. A substantial number of agricultural and horticultural scientists, nutritionists, crop protection specialists, and development practitioners will receive training tailored to their disciplines and locales, and the public sector capacity for plant breeding and seed production will be increased and made more functional worldwide.

Integrated action in research, capacity development, and positive policy creation to deliver sustainable agricultural intensification at the landscape scale is required if food and nutritional security is to be attained through smallholder agriculture and other rural enterprises. Farmers, extension systems, universities and national research institutes, NGOs, the private sector, and international agencies such as the United Nations FAO, the Consultative Group for International Agricultural Research (CGIAR), and the Association of International Research and Development Centers for Agriculture (AIRCA) need to work together to help communities move from poverty to prosperity.

We must abolish not only hunger, but malnutrition as well.

Most importantly, we need to get away from the simplistic "Green Revolution" way of thinking and ensure that all dimensions of agricultural research and development receive appropriate, balanced, and stable investment. **The old policy of allocating the lion's share of resources principally to staple cereals must change to encompass a broader spectrum of crops and to reflect our deeper understanding of the role of nutrition in health.** In addition, all scientific disciplines require support, even those that may be less popular than the currently favored biotechnologies. More emphasis is needed on applied disciplines, such as plant breeding, agronomy, pest management, and home economics, now and into the future.

Managing to feed the world in 2050 is one thing; however, if we fail to nourish it at the same time, we will have placed the well-being of a large proportion of the world's population at significant risk of sub-optimal health and reduced quality of life. We must seek to abolish not only hunger, but malnutrition as well.

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Managing Water for Food Security

Chandra A. Madramootoo, P.Eng.

It is sometimes remarked that the world is in the midst of several interconnected crises—a food crisis, a water crisis, and an energy crisis. All of these crises are magnified and compounded by the effects of a changing climate and the more frequent occurrences of floods and low rainfall in several parts of the world. World hunger and malnutrition will regrettably increase if we fail to conserve our precious and fragile land and water resources, and better manage the energy inputs to the agricultural system. Agricultural and biological engineers are well positioned to find solutions to these global problems. Sustainable management of natural resources, development of bioenergy systems, and the use of biologically engineered systems to mitigate the impacts of climate change are at the heart of the solutions.

The world population is expected to increase to about 9 billion by 2050, and the United Nations FAO projects that world food supplies will have to at least double to meet the increased demand. In some regions, such as Southeast Asia, food supplies may have to increase by as much as 75%. The land base for increasing food production is limited, particularly in the developing world, and further land expansion will lead to deforestation, soil erosion, and loss of soil organic matter. Destruction of savannah lands will also negatively impact biodiversity. There is already concern in North America and Europe that the drainage of sensitive wetlands for agriculture not only alters hydrologic regimes but also destroys waterfowl habitats as well as important vegetative and aquatic species.

Many parts of the world, including the U.S., the Middle East and North Africa, and the semi-arid tropics of India, China, Africa, and Central America, are already facing severe water scarcity. Crop production in these regions is limited by low and unpredictable rainfall. Crop yields are often too low to provide household food and nutrition security, let alone augment household income through the sale of surplus commodities. Continual depletion of both surface water and groundwater, due to a combination of high consumptive use and low recharge rates, puts both rainfed and irrigated crop production in jeopardy.

New water management technologies and more efficient delivery and on-farm water systems will be at the heart of the solutions to global food security.

On a global scale, irrigation water use accounts for just over 70% of total freshwater withdrawals. There is also a growing use of groundwater for irrigation in areas where surface water does not exist or is scarce. The countries with the largest areas under groundwater irrigation are India (39 Mha), China (19 Mha), and the U.S. (17 Mha). However, given concerns about the sustainability of large irrigation water withdrawals, in light of competing economic and environmental demands for water, and rainfall variability due to climate change, it is essential that the irrigation sector develop more innovative techniques to conserve water, and use less water to produce more biomass.

There are 1500 Mha of cropland globally, of which about 300 Mha are irrigated, with the remainder being rainfed. It is remarkable that these 300 Mha of irrigated land, about 20% of global cropland, produce approximately 40% of the world's food. The importance of irrigated agriculture for food security is therefore well demonstrated. In order to improve the performance of irrigation systems, the major push is toward improved canal delivery systems, moving from a supply-driven irrigation network to a demand-driven system with gated controls, and also pipeline conveyance systems in some cases. At the field scale, where possible, there are conversions from flood and surface irrigation to drip systems, and low-energy, low-pressure application (LEPA) sprinklers. Another recent innovation is the implementation of precision irrigation, in which water application is matched to soil type, crop type, and crop growth stage.

Precision irrigation technology in Lethbridge, Alberta, Canada.

The current evolutionary stage in center-pivot systems is variable-rate irrigation (VRI), in which management zones are defined by several parameters, including soil physical and chemical properties, land elevation, and farming practices. Using solenoid valves and electronic controllers, the application rate can be varied by management zone. The travel time of the pivot can also be regulated to vary the application by management zone. One benefit of VRI is that low elevations in the field are not overirrigated and higher elevations are not underirrigated. Consequently, salinity and waterlogging are better controlled. More uniform crop yields can be achieved, and there is less leaching of agrochemicals to the groundwater. The improved irrigation uniformity made possible with VRI leads to water savings.

There is also potential to achieve further savings through the use of soil water sensors to better schedule irrigation applications. The goal is to use soil water and crop canopy sensors to monitor water stress in plants, and then input these data into climate and crop growth models to predict irrigation requirements on a real-time basis. Water savings in the range of 25% to 30% could be achieved through the implementation of the technologies that have been described here, and these technologies already exist.

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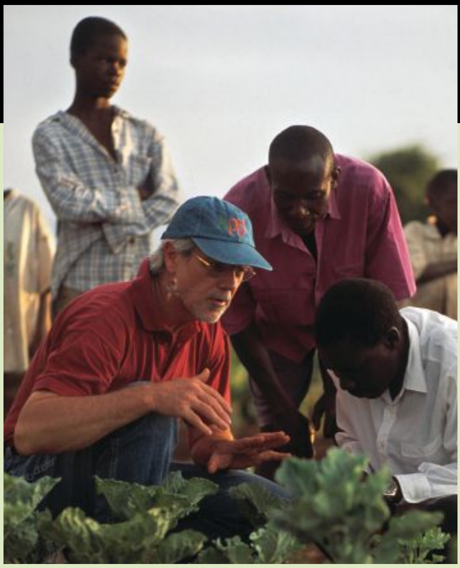
Top photo by Jack Dykinga, courtesy of USDA-ARS.
Bottom photo by the author.

Rethinking Food Systems

Hans R. Herren

Knowledge dissemination in a form appropriate to smallholders is key to lifting the rural population of developing countries out of hunger and poverty. The Farmer Communication Programme in East Africa is addressing farmers though various channels to ensure that the messages reach their target.



The dominant narrative for nourishing the world in 2050 tends to focus on the need to double production in order to keep up with current population projections of 9 billion people, as well as changing consumption patterns. While intensive agriculture has delivered impressive yield increases in the past, the focus on yield maximization has exhausted its resource base for the long run, with an estimated 1.9 billion ha of land already affected by degradation, at an annual cost of $40 billion. In our work with key actors in agricultural development from the field to the policy levels, Biovision Foundation and the Millennium Institute aim to move beyond this reductionist narrative by building on the paradigmatic shift of the International Assessment of Agricultural Knowledge, Science, and Technology for Development (IAASTD), which outlines that business as usual, i.e., the Green Revolution model, is no longer an option.

Supported by the UNEP's 2011 Green Economy Report (www.unep.org/greeneconomy/GreenEconomyReport/tabid/29846/Default.aspx), agro-ecological approaches in particular are predicted to produce higher and more stable yields, better soil quality, and ultimately more calories, while significantly reducing water use, land under cultivation, deforestation, and contribution to climate change. The report used the Millennium Institute's Threshold 21 model (www.millennium-institute.org/integrated_planning/tools/T21/index.html), a system dynamics tool for describing and analyzing complex systems in support of integrated development planning.

Currently, 842 million people are suffering from hunger—even though we already produce twice the number of calories necessary to feed the world's population. At the same time, obesity has doubled since 1980, and an estimated 1.4 billion adults are overweight. As a result, future pathways to nourish the world by 2050 need to consider the complexities of our food systems: who should produce which food where and how?

Food system analyses reveal that large efficiency gains can be obtained from production to consumption. On-farm losses amount to 40% of total losses in developing countries, while household and municipal consumption account for up to 50% of total losses in developed countries. These losses of global calories are aggravated by changing consumption patterns—particularly meat-based diets reliant on animal feed—and by channeling food crops to biofuel production. **Therefore, what we need are sustainable solutions to address pre-harvest and post-harvest losses in developing countries while simultaneously decreasing waste in the global north.**

To address these challenges, we are working with national governments in three countries (Ethiopia, Kenya, and Senegal) to introduce system dynamics modeling and scenario approaches to support multi-stakeholder assessments of their agriculture and food systems. These pilot programs are aimed at developing guidelines for country-led assessments of agriculture and food systems, as recommended by the Rio+20 summit, which emphasized the need for sustainable agricultural policies to improve food security and eradicate hunger with regard to the challenges of climate change, natural resource limitations, and changing demand. These activities will also inform the Sustainable Development Goals (SDGs) up to 2030 that are now being developed.

In the framework of our systemic approach to development, we are also working with scientists and smallholder farmers in East Africa to establish sustainable and innovative production alternatives. With our long-term partners, such as the International Centre of Insect Physiology and Ecology (*icipe*) in Kenya and national research organizations, we have successfully implemented projects that showcase how knowledge-intensive solutions dramatically improve farmers' yields and income.

One example is the Push-Pull method, adopted by over 90,000 farmers in East Africa (www.push-pull.net). It builds on intercropping corn with *Desmodium* as a nitrogen-fixing legume, which repels pests and eliminates *Striga*, while the volatiles of a border crop, such as Napier grass, attract the pests. Additional benefits include control of soil erosion and increased soil fertility, fodder, and dairy production. Push-Pull is an exemplary agro-ecological approach, the more so when included in agroforestry systems and extended beyond corn. Yields are easily doubled or even tripled with such systems without additional off-farm inputs, while the crop's resilience in the face of weather extremes and pests is significantly improved.

We also ensure that such knowledge-intensive innovations are disseminated to farmers via the Farmer Communication Program (including the Infonet platform, www.infonet-biovision.org). As a complementing element in the circle from research to field testing and dissemination, we also bring these achievements into the policy development area for evidence-based decision-making.

Despite these efforts, and the evidence that agro-ecological approaches are the most promising way forward for environmental, social, and economic reasons (for example, the rate of return for biological control of the cassava mealybug in Africa was $247 for every $1 invested, discounted over 20 years; it benefited over 200 million farmers and saved an estimated 20 million lives), agro-ecological research and its dissemination remain grossly underfunded compared with investments in seed breeding. To nourish the world in 2050, we advocate a systemic, holistic, and causal approach in dealing with the constraints and complexities encountered along the food value chain, from production to consumption.

Hans R. Herren, (wearing cap in above photo) entomologist, farmer, and development specialist, is President of the Biovision Foundation, Zurich, Switzerland (www.biovision.ch), and President of the Millennium Institute, Washington, D.C., USA (www.millennium-institute.org). He received the 1995 World Food Prize and the 2013 Right Livelihood Award.

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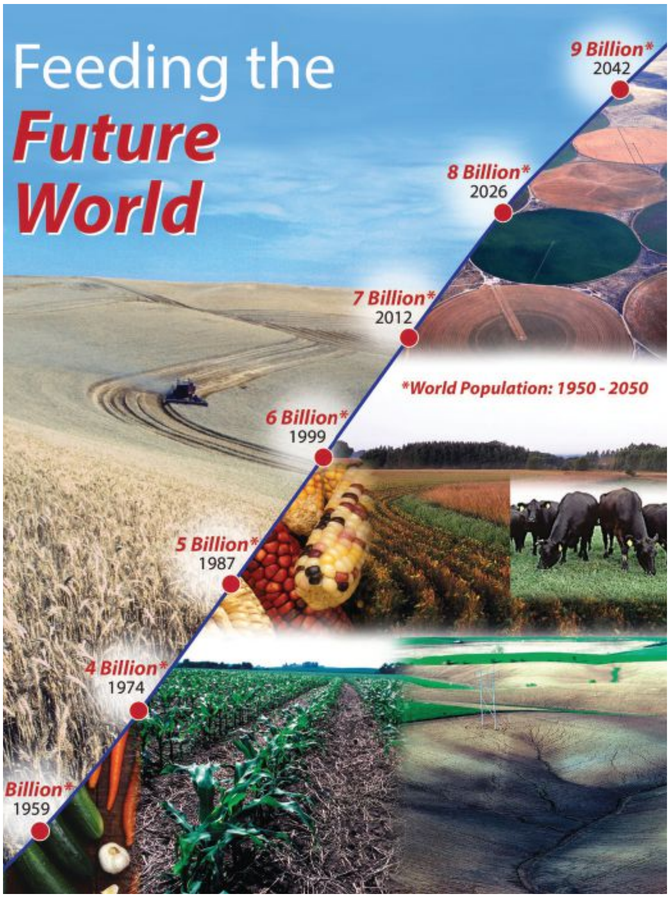
Feed the World? First Let's Refocus Research

Jerry L. Hatfield

The estimates for feeding the world in 2050 range from increases of 60% to 110% above our current production levels for grain crops. The more interesting estimate for feeding the world by 2050 will require a greater than 100% increase in caloric production. Over the past 20 years, and more intensively over the past 10 years, I have begun to focus on what will be required from our agricultural systems to produce enough food to feed the ever-increasing population with the increasing variations in temperature and precipitation. At the same time, there has been considerable focus on yield and potential yield in the discussion of how to feed the world, with particular attention given to yield-limiting factors. However, those discussions tend to lead us to search for a single factor affecting yield. In reality, **there are multiple paths in our search for sustainable food production that all need to be explored to find solutions to meeting our food needs by 2050.**



The projected population increase from 1950 to 2050.

Instead of focusing exclusively on yield, we need to think in terms of production efficiency (i.e., how much we produce per unit of input supplied) and in terms of business (i.e., the return on investment of agronomic decisions). What is the water use efficiency, nitrogen use efficiency, and radiation use efficiency of different crop production systems, and how can those efficiencies be improved through a combination of genetics and management systems? To address this issue, I propose that we expand our thinking and use genetics x environment x management (G x E x M) as the framework for developing and evaluating new production systems. If we begin to address food production with a systematic approach—how genetic resources respond to management systems under different environments—then we will have a clearer definition of what limits yield. In other words, to understand what limits yield, we need to focus our attention on the environmental and management interactions that contribute to yield.

One of the critical pieces of this puzzle is the role that enhanced soil quality plays in crop production. We have lost sight of the fact that healthy soil provides water and nutrients and is therefore an essential component of an efficient production system. Our recent study on yield gaps and yield relationships in U.S. soybean production reported that mean county-level soybean yield was positively related to soil quality, as defined by the USDA-NRCS National Crop Commodity Productivity Index (NCCPI). When crops are grown under rainfed conditions, which are typical of most of the world, yield increases as soil quality improves. We are not going to solve the production problem throughout the world unless we address the soil problem and begin to improve the capacity of the soil to produce crops efficiently.

In our focus on yield, we have also neglected the quality of the product. We need to reorient our attention to the current state of grain and produce quality, and the factors that affect overall quality. A recent letter in the journal *Nature* on observed dietary deficiencies caused by increasing atmospheric CO_2 should serve as a call to devote more attention to the nutritional quality of our produce. An earlier study on global food demand and the sustainable intensification of agriculture based its projections on the caloric requirements for feeding the world, rather than the tonnage of produce. To create food security, we need to focus on the factors that create nutritious and calorie-dense food products.

It may seem that there is little we can to do to meet the needs of the world population in 2050, and that the problem is therefore insolvable. It's true that we cannot be satisfied with incremental improvements in production. Instead, we need to think about how we can increase our food production dramatically. I believe that part of the solution will be refocusing our research as a more holistic effort, bringing geneticists, agronomists, environmentalists, and social scientists together to develop new farming systems that are adaptable by the producers in specific areas. That won't be as easy, but it is achievable, and it will allow us to develop and sustain the next agricultural revolution. That is the task that we should embrace.

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Further reading

Egli, D. B., and J. L. Hatfield. 2014. Yield gaps and yield relationships in central U.S. soybean production systems. *Agronomy J.* 106(2): 560-566. doi:10.2134/agronj2013.0364.

Myers, S. S., et al. 2014. Letter: Increasing CO_2 threatens human nutrition. *Nature* 510(7503): 139-142. doi:10:1038/nature13179.

Tilman, D., et al. 2011. Global food demand and the sustainable intensification of agriculture. *PNAS* 108(50): 20260-20264. doi: 10.1073/pnas.1116437108.

Top page photo by Charles Merfield.
Mid-page illustration by Michael Marti and the author, photos courtesy of USDA-ARS.

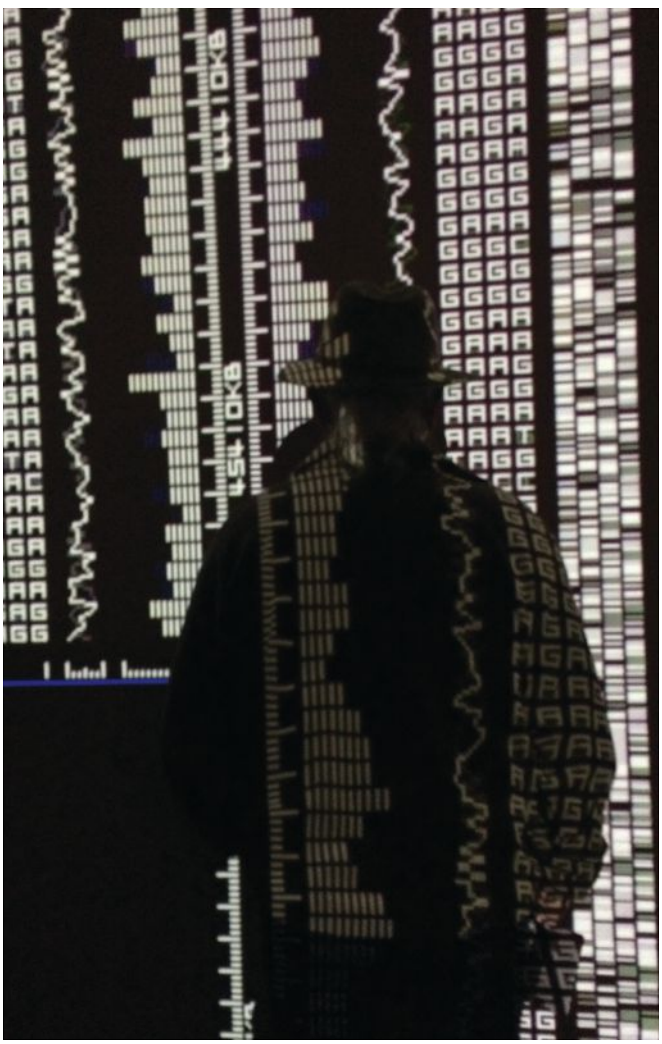
The Transdisciplinary Conundrum

Graeme Hammer

Achieving global food security has many facets. While socioeconomic and political issues, such as development of and access to markets, improving infrastructure for transport of agricultural produce, and stable governance systems, are all critical, we must also produce more food and do it sustainably in both developed and developing countries.

Research will be essential to this challenge, especially for removing impediments to improved production for resource-poor farmers in developing countries. This includes market development, access to agronomic knowledge, and investment in the technology and reliability of national support systems. We must also improve the sustainability of production systems in developed countries by becoming more efficient in the use of energy, water, and nutrients. In all cases, maintaining the health of soil and water resources is paramount.

In my own area, crop ecophysiology and modeling, I work in developing and developed economies with a focus on crop design and management for improved crop adaptation. I'm particularly interested in potential technologies for advanced agricultural systems because that is where higher food prices—which are likely—will drive the research that increases productivity in the coming decades.



The author awash in a data stream inside an installation at the Museum of Old and New Art, Hobart, Tasmania, photographed in January 2013.

Crop growth and yield are the ability of the crop to capture resources—light, water, and nutrients—and the efficiency with which the crop converts these resources into biomass and harvestable product. Crop growth at critical developmental stages largely determines the proportion of the crop that ends up as yield, especially for our dominant cereal crops. So far, our interventions, through genetics and crop management, have targeted—and mostly optimized—the capture of resources, its timing through the crop life cycle, and the proportion of total growth allocated to harvestable product, all of which determine yield and profit.

Because the approaches to improving resource capture by field crops are better understood, if not fully known or implemented, than the approaches to improving resource use efficiencies, we should now focus more research effort on the latter. The substantial differences in resource use efficiencies between crop species (e.g., corn vs. sorghum) strongly suggest that these efficiencies can be improved. One way to do this is through the genetic design of plants; however, to date, there has been little genetic impact on the fundamental resource use efficiencies of plants. Here, then, is a breakthrough opportunity for science: Can we redesign plants to improve their resource use efficiency? And by doing so, can we take advantage of the rising level of atmospheric CO_2?

As a first step, measuring and understanding the physiological and genetic basis of the existing variability in resource use efficiencies is critical. Fortunately, there has been a continuing revolution in genetics and the technologies for genome mapping, sequencing, and editing. Along with this is an emerging impetus for high-throughput phenotyping to amass voluminous data on plant attributes.

And that is where **we face a transdisciplinary conundrum. Improving the resource use efficiency of crops could be a transformational improvement in global agriculture, but achieving that transformation will require a broad, transdisciplinary effort.** Advanced phenotyping and genotyping technologies are appropriate tools, but the transformation will also require know-how about what to measure, how to measure it, and which genetic designs to use.

No single discipline can achieve this alone. In fact, as we face a historic challenge, the traditional separation of disciplines that is entrenched in scientific culture is restricting our progress. A new culture of connectivity is required, giving us the ability to operate effectively and openly across disciplines—engaging with, and challenging, each other. Feeding the world in 2050 demands it.

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Three Paths to Pursue

Craig Gundersen

A central focus of the College of Agricultural, Consumer, and Environmental Sciences (ACES) at the University of Illinois is to reduce food insecurity across the world. I participate in these efforts as the Soybean Industry Endowed Professor in Agricultural Strategy in the Department of Agricultural and Consumer Economics and as the Executive Director of the National Soybean Research Laboratory (NSRL). My own research interests concentrate on the causes and consequences of food insecurity and the evaluation of food assistance programs. At NSRL, we facilitate research that improves the yields and profitability of farmers in Illinois, we promote the effective use of soybeans in animal and human nutrition, and we further the use of soybeans for human nutrition in dozens of lower-income and lower-middle income countries across the world.

Field plots of soybeans.

Hundreds of millions of people across the world are food insecure, and many more are at risk of being food insecure. Alleviating this food insecurity and the resulting health problems and other consequences is the most important challenge facing the world today, and it will be even more daunting as the population increases to 9 billion by 2050. Here, I articulate three paths that we can pursue toward this goal.

Increased use of soybeans in human nutrition

Protein malnutrition is a common problem in low-income and low-to-middle income countries. For most of those suffering from protein malnutrition, diets with animal sources of protein are too expensive. When this is the case, soybeans are an excellent alternative, as they are by far the most cost-effective source of protein, they constitute a complete protein, and they can be readily incorporated into existing local cuisines. Regarding that last point, as an example, NSRL is heading up the nutrition component of a recent multi-million dollar grant from USAID to the University of Illinois to establish the Soybean Innovation Lab (SIL), which is designed to promote the production and use of soybeans in Feed the Future countries (www.feedthefuture.gov).

For the SIL, we at NSRL are promoting soy in human nutrition through two mechanisms. First, in partnership with the World Initiative for Soy in Human Health (WISHH), we are setting up Soycows and Vitagoats, which are small-scale production methods to produce soymilk. Second, we are establishing new pathways to introduce in-home processing and utilization of soybeans in partnership with International Institute of Tropical Agriculture (IITA). Since soybeans are not generally part of the diet in the countries that the SIL addresses, successful establishment of soybeans will require instruction in processing and the development of appropriate recipes for local cuisines.

Allowing the use of effective technologies

There is a limited amount of land that can be utilized to feed the world and, as the number of people increases, this will become an ever more important constraint. To address this constraint, farmers across the world need to be able to use the most effective available technologies and, currently, this entails the use of genetically modified seeds. Through the use of these technologies, farmers can dramatically increase yields while using less inputs and, hence, be more sustainable. A key result is that more food at lower prices is made available to those with limited resources.

Unfortunately, there are various groups around the world who seek to limit the use of genetically modified seeds, and they have been successful in meeting this objective in some places. In the near term, this has resulted in millions of people around the world being mired in food insecurity. In the longer term, if these groups continue to succeed, millions of people will continue to be food insecure and, more broadly, research to generate even more innovative genetic modifications will be discouraged. If a country is interested in ending malnutrition across the world, eliminating all impediments to advanced agricultural technologies, including genetically modified products, is essential. Of particular importance are technologies related to soybeans, given their role as a key provider of protein in both human and animal consumption.

Encouraging free trade

The benefits of free trade for the well-being of low-income people across the world are well established. Alongside other benefits, free trade ensures lower prices, less price volatility, and the allocation of scarce inputs to their most effective uses. As poor people are most negatively affected by high food prices and by food price volatility, free trade is especially beneficial for them. Despite the proven benefits associated with free trade, there is continued resistance to opening up borders for trade. For those who want to reduce food insecurity in both their own country and in other countries, promoting free trade and removing barriers to free trade are both essential.

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Top photo by Scott Bauer, courtesy of USDA-ARS.
Mid-page photo by the author.

Some Thoughts from across the Pond

Dick Godwin

In the U.K., several issues were brought to a head by the 2011 publication of the "Future of food and farming" report—a foresight report commissioned by the then chief scientist for the U.K. government, Sir John Beddington (www.gov.uk/government/publications/future-of-food-and-farming). Sir John referred to the situation that the report describes as the "the perfect storm." The report highlighted six major concerns:

- Global population increase.
- Changes in the size and nature of per capita demand.
- National and international governance of the food system.
- Climate change.
- Competition for key resources.
- Changes in the values and ethical stances of consumers.

The report also set five challenges:

- Balancing future demand with sustainable supply and ensuring affordability.
- Ensuring stability of supply and protecting the most vulnerable from volatility.
- Achieving global access to food and ending hunger.
- Managing the contribution of the food system to the mitigation of climate change.
- Maintaining biodiversity and ecosystem services while feeding the world.

My colleagues and I read the report with much enthusiasm, only to be disappointed that there was no mention of the role of engineering! We made an appointment to see Sir John, who agreed with us and asked for a response. As a result, "Agricultural engineering: A key discipline enabling agriculture to deliver global food security" was published by the U.K.'s Institution of Agricultural Engineers (IAgrE) in 2012 (www.iagre.org/sites/iagre.org/files/repository/IAgrEGlobal_Food_Security_v2_WEB.pdf).

The U.K. agricultural industry also rose to the challenge, and "Feeding the future" was published in 2013 (http://feedingthefuture.info/report-launch). This industry report covers the following topics, among others:

- The use of modern technologies to improve the precision and efficiency of management practices.
- The use of systems-based approaches to better understand and manage the interactions between soil, water, and crop/animal processes.
- The development of integrated approaches for the effective management of weeds, pests, and diseases.
- The training and professional development of researchers, practitioners, and advisors to promote delivery of the above.

"Man has only a thin layer of soil between himself and starvation."

As a result of this on-going discussion, the U.K. government has launched its "agri-tech" strategy (www.gov.uk/government/publications/uk-agricultural-technologies-strategy). We are still not sure how engineering will be represented; however, the strategy reflects the issues raised by the "Feeding the future" report. The recent call for consortia to provide centers for agricultural innovation cites the need for cross-disciplinary centers in "precision agriculture, engineering, and sensor technologies."

This brings me to a major problem: the "skills gap"—the void produced by the 20 years of decline in agricultural research, development, and extension, which saw many mid-career agricultural engineers leave the profession as world-class centers of excellence were closed. Their absence makes it difficult for recent graduates and postdocs to find experienced mentors. Another concern is the lack of firsthand experience in practical agriculture of many current postdocs. While I fully support the need for good science and publication, the focus on "publish or perish" in our universities and research stations can distort the mission. **We will not feed the world on scientific publications alone, a fact that is sometimes overlooked by administrators who focus only on achieving the best academic standing for their university.**

There are plenty of opportunities to work with other professions. The only barriers are time, money, and above all good leadership and governance. The challenges are enormous, and because there are so few of us, we all need to work together, using our complementary skills, to feed the world. However, by working together, we will achieve this goal. Engineering solutions can deliver many of the short-term benefits that we so desperately need, thereby buying time for the benefits of the so-called "pioneering research" to come to fruition.

In particular, the management of our soil and water resources is crucial, including alleviation of soil compaction as machine size and weight increase, improved management of scarce irrigation water, and maintenance and development of affordable land drainage and soil conservation measures. We also need to focus on reducing post-harvest losses, which are often in excess of 40% for a variety of reasons, from consumer wastage in the affluent world to the lack of knowledge, capital, and infrastructure in poorer regions.

I leave you with the reminder that we grow all our food on less than 3% of the world's surface, so managing our soil and water resources is crucial. This point is reinforced by two classic quotations—from Franklin Delano Roosevelt: "The nation that destroys its soils destroys itself," and from the much-quoted philosopher Anonymous: "Man has only a thin layer of soil between himself and starvation."

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A New Paradigm for Feeding the World in 2050

The Sustainable Intensification of Crop Production

Theodor Friedrich

When the Food and Agricultural Organization (FAO) of the United Nations was founded in 1945, it was with the objective to fight hunger in the world. Since then, some progress has been made. The first of the Millennium Development Goals—to halve the proportion of hungry people in the world by 2015—appears within reach. At present, hunger along with poverty is more a problem of access to food than of availability. Therefore, hunger is being successfully addressed in many countries by political will and social programs. However, for the expected population of 9.2 billion in 2050, global food production will have to increase by about 70%, a conservative estimate considering the increased demand for animal products and bioenergy and the threats from climate change. Despite this challenge, FAO has revised its overall goal from reducing hunger to eradicating hunger. We can assume that FAO member countries, in accepting this change, are not pursuing an impossible target.

There is little hope of achieving the necessary production increase from expanding the cultivated land area. More than 80% of the necessary production increase will have to come from yield increases. Yet, the yield increases for all major food crops are declining. Therefore, this challenge will not be met by continuing with a concept of farming that caused the problem in the first place. The problem is not in the genetic potential of crops or the lack of production inputs. Instead, the problem lies in the degradation of natural resources and their yield-related functions, which do not allow closing the yield gap anymore.

Therefore, **FAO has proposed a different paradigm for agricultural production: sustainable intensification, as described in the book *Save and Grow* (www.fao.org/ag/save-and-grow). Sustainable intensification means achieving the highest possible production, applying all necessary technologies, while keeping the environmental impact below the threshold of natural recovery.**

FAO would not propose this paradigm change if it did not have "proof of application" that it actually works for farmers. Agricultural production can only be considered sustainable if the soil health and productive capacity are maintained in an optimal condition. Over the past millennia, agricultural land use globally has led to physical, chemical, biological, and hydrological degradation of the soil, and this process continues unabated on most farm lands. This is true for farms of all sizes, climatic regions, and economic development levels.

By reducing the turnover time between harvest and seeding of the subsequent crop, conservation agriculture enables farmers in climates with restricted growing periods to grow an additional crop in the same season.

The dominant global farming paradigm is based on mechanical tillage. In this paradigm, the "best practices" for crop, soil, nutrient, water, and pest management are the technical state of the art and are presumed to be suitable for obtaining high production with limited environmental damage. However, in many cases, soil degradation and environmental damage can only be controlled, not avoided, and this damage is generally accepted as an inevitable side effect of farming. This view is now being challenged, and it is increasingly considered outdated. Tillage-based farming practices cannot meet the combined objectives of production intensification with ecosystem services that are now being demanded by society. In the case of the soil, the degradation and erosion caused by tillage are always greater, by orders of magnitude, than the natural formation of soil. Hence, tillage systems cannot be sustainable. A long list of literature explores this problem, from Edward Faulkner's *Ploughman's Folly* (1943) to the more recent *Dirt: The Erosion of Civilizations* by David Montgomery (2007).

The logical response to this challenge is a farming system that does not mechanically disturb the soil and maintains the soil in a healthy state—a no-till system with biologically and ecologically active soil. Analyzing farmers' experiences with no-till around the world, FAO has come up with a definition for such a system, commonly known as conservation agriculture (CA), based on three interlinked principles for any land-based production system:

- Minimum or no mechanical soil disturbance (permanently).
- Permanent organic soil cover.
- Diversification of species.

When implemented correctly, CA delivers on multiple objectives: it increases yield and production in a sustainable way, closing the yield gap with reduced inputs over time, while enhancing ecosystem services. It is environmentally, economically, and socially sustainable and highly productive, and it responds to the demand for climate change adaptation and mitigation. I have seen many farmers on all continents improve their livelihoods and happiness after adopting CA on their farms. With CA, FAO had a sound basis for sustainable intensification, and hence FAO has been promoting CA around the world, along with a growing number of organizations and institutions. Globally, CA is growing exponentially at 10 million ha per year, having reached 155 million ha in 2013, which represents 11% of global cropland. In some countries, CA is now the dominant farming system, and the oldest CA farms date back over 50 years.

Obviously, despite CA's many advantages, such a complex paradigm change in farming requires continued policy and institutional support for it to spread fast enough to help meet the challenge of feeding the world in 2050. This challenge is still facing us, and it is a question of political will, as is the eradication of hunger at the present time. Given that political will, there is no question that the challenge to feed the world in 2050 can be met with conservation agriculture, without the need of technological miracles that are yet to be invented.

ASABE Member Theodor Friedrich is co-founder of FAO's conservation agriculture initiative and for more than a decade has led FAO's global work on CA. He currently serves as FAO's representative in Cuba; theodor.friedrich@fao.org.

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Soil: The Key to Feeding the World in 2050

Don Erbach

How will the world's population be fed in 2050? Soil-based plant production has fed humanity throughout history and will likely continue to be our primary food source. Although most people think little about soil, productive land is critical to human well-being. Earth has a soil resource easily sufficient to produce food for the world's growing population, but only if attitudes, policies, and practices allow that resource to be properly managed and effectively used.

The past 36 years have seen important advances in plant production. Significant technological advances have been made in plant genetics, mechanization, pest control, and nutrient management—advances that have resulted in major increases in yields and improvements in crop quality. It seems reasonable to expect similar productivity improvements to continue through 2050.

Although most crops are grown in soil, plants really do not care about soil. In fact, they can be grown perfectly well without soil in controlled environments, such as hydroponics and aeroponics. However, plants do care about water, nutrients, light, heat, and physical support. Outdoor culture in good-quality soil provides these growth requirements effectively, efficiently, and economically. Controlled environment agricultural production will increase but, for economic reasons, most plant production will continue to be soil based in a natural outdoor environment.

Although it's as common as dirt, soil is an extremely complex physical-chemical-biological material, the condition of which may be subjectively characterized as its tilth. Soil tilth is a result of a combination of many factors, some of which are particle size distribution, aggregate size distribution, pore size distribution, water holding capacity, degree of aeration, pH, and organic matter content. Soil with good tilth is well suited for crop production.

The overall quality of the world's soil resource is, and will continue to be, critical to feeding the population. Better-quality soil can produce more and better-quality food, along with providing greater economic returns to farmers and lower prices for consumers.

Unfortunately, at present, much of the world's soil is, for a variety of reasons, of poor tilth. Fortunately, a soil with poor tilth can be physically, chemically, or biologically modified to improve its condition. Improving soil characteristics, such as by increasing soil organic carbon, plant rooting depth, and water holding capacity, can improve production efficiency. Depending on the depth and nature of the modification required, treatment may be difficult and expensive. As the demand for high-quality soil increases, more extensive modifications will become economically realistic, especially for production of high-value specialty crops on small land areas.

Soil is the key, but it needs some help.

A cause for concern is the amount of agricultural land being converted to commercial, residential, transportation, recreational, and other uses. If the conversion of land from agriculture continues, as is likely, then future food production may be jeopardized. Without a serious food shortage, famine, or other significant event that focuses attention on the importance of soil, the next 36 years will see agricultural land area decrease and soil quality degrade.

Water is also a problem. Insufficient water seriously limits crop production. Rainfed agriculture is at the mercy of timely rainfall, and irrigated agriculture depends on a dependable, economical, and adequate supply of water. Even though the amount of water on Earth is huge, the supply of fresh water is limited, and it is not always available in adequate amounts at the right time and in the right place. Desalination of seawater, powered by sustainable, renewable energy, must be developed to alleviate fresh water shortages. With the adoption of appropriate policies and development of the necessary infrastructure, sufficient water for food production, and other needs, can be supplied.

Public and political awareness of the importance of maintaining a high-quality world soil resource must be heightened. Supportive government policies are essential for ensuring that agriculturally important land remains agricultural land, that soil is managed effectively, and that its quality is enhanced.

Proper management of the soil resource will require expanded efforts to understand soil and to develop practices for sustainable soil resource management. Realistically, the complexities of soil will cause this progress to be slow.

How will the world's population be fed in 2050? Soil is the key, but it needs some help. If properly managed, the world's soil resource will be adequate and capable of producing sufficient food to meet nutritional needs. However, for all to be properly fed in 2050, political, ethnic, nationalistic, class, economic, religious, and other strife must not interfere with efficient use of soil to produce food and must not hinder distribution of that food. Unfortunately, this is where the dream of Utopia begins. Time will tell.

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Sustainability Starts with Research

Reza Ehsani

My personal involvement with food production started when I was a teenager, tending all kinds of row crops on our family farm. That experience taught me about the challenges involved in farming. While I was working on my PhD at the University of California, Davis, I learned about new management techniques, such as precision agriculture, and was introduced to the production of high-value crops, i.e., fruits and vegetables, rather than the row crops that I was familiar with. A healthy diet requires fruits and vegetables, but these foods are relatively expensive in the U.S. because they are labor-intensive, and the cost of labor is high. Although there are many opportunities for automation, the production of fruits and vegetables is the least-mechanized area of modern agriculture.

My professional involvement in food production started with developing machines and advanced equipment for reducing the production costs of tree crops. That includes improving the efficiency and productivity of mechanical harvesters for citrus fruit, as well as developing tools for optimizing production using data-driven management strategies for crop inputs. In addition to research, I have been involved in extension outreach education to transfer new knowledge in fruit production to growers. In particular, my contribution toward the goal of sustainable food production has been in detecting and managing the spread of crop diseases.

The devastating effects of citrus greening disease (also known as Huanglongbing, or HLB) on citrus production in Florida is a prime example of how destructive a crop disease can be, and how a single disease can endanger an entire industry. HLB is a bacterial infection caused by *Candidatus Liberibacter asiaticus* (CLas). The spread of HLB threatens the future of Florida's $9 billion citrus industry. Citrus production in Florida has dropped from 240 million boxes ten years ago to 115 million boxes last year, and HLB is the major factor behind this decline. If we don't find a treatment, and soon, many growers believe that the Florida citrus industry will simply cease to exist.

To prevent the spread of a disease like HLB, early detection at the asymptomatic stage is critical. Prevention is the best way to control an epidemic. One of my areas of research involves detecting diseases that affect fruit trees, such as HLB, at early stages using imaging with an unmanned aerial vehicle (UAV). The Federal Aviation Administration will soon integrate UAVs into the U.S. airspace, and agriculture will likely be the biggest market. UAVs are an excellent tool for crop monitoring, and they could significantly reduce the crop scouting costs for growers. Most importantly, by detecting diseases at early stages, the fast spread of plant diseases could be prevented before crop loss occurs.

For treating pests and diseases, my colleagues and I are focusing on physical control methods instead of chemical controls. For example, in the case of HLB, we are using thermotherapy to prolong the life of infected trees. Our prototype machine covers individual trees with a collapsible hood and then uses steam to kill the HLB bacteria. It is a safe, chemical-free technique with no ill effects on the fruit. It is also environmentally friendly. There are also opportunities to use similar techniques to enhance nutrient uptake and improve irrigation efficiency.

However, **research takes time and costs money. Sustainable agriculture will not be possible without supportive government policies. Agricultural development should be an international priority, and policy makers should work to promote environmentally friendly and sustainable production. Funding for agricultural research needs to be increased, and special funding should be made available for developing sustainable technologies.**

The factors that will limit sustainable food production in the near future are the decreasing availability of land and water for agriculture, the exponential increase in the spread of pests and diseases, and the absence of a new generation of farmers—young, well-trained, and innovative. Incentives should be created to bring that next generation into agriculture. Finally, consumers need to be better informed about how agricultural products are grown, to encourage popular support for sustainable practices. In summary, to feed the world by 2050, a lot of steps need to be taken. We must start now.

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Top photo by Scott Bauer, courtesy of USDA-ARS.
Bottom photos by the author.

Heat treatment of an HLB-infected citrus tree.

The Rise of Vertical Farms

Dickson Despommier

I began my professional career as a laboratory scientist in the field of medical parasitology, investigating the molecular biology of an infectious foodborne nematode, *Trichinella spiralis*. During the course of my studies, over more than 30 years, I became increasingly aware that food safety and security are linked to issues of food availability, and ultimately to agricultural practices.

Now that I am no longer at the research bench, my attention has shifted to understanding the details of ecosystem ecology and the negative effects that traditional farming is having on ecosystem services and functions. I have also become aware that there is a direct connection between rapid climate change, fossil fuel use, and deforestation that favors the establishment of more farmland. That is when I began exploring potential solutions that could reduce the rapid (i.e., anthropogenic) part of climate change. The concept of raising significant amounts of food indoors using hydroponics and aeroponics (collectively known as controlled environment agriculture, or CEA) appeared to offer great promise in that regard.

CEA can be carried out anywhere on Earth, it is not affected by the weather, it uses significantly less water than conventional farming, it produces no agricultural runoff, and it can produce a wide variety of crops indoors at commercial scale. I began to incorporate these concepts into my teaching, and after some ten years of brainstorming in the classroom, the idea of the vertical farm became a reality. As of 2014, there are many examples of vertical farms in Japan, Korea, Singapore, Sweden, and the U.S., with many more in the planning stage.

In the coming years, I expect that there will be hundreds, even thousands, of vertical farms in operation throughout the world. This is because retrofitting disused buildings into functional vertical farms has become much easier. The recent dramatic increase in the energy efficiency of LED grow lights—from 28% to 68%—is also very encouraging and can greatly reduce the energy costs of indoor farming. I have been fortunate to be in on the ground floor of the vertical farming movement, so I am often asked to give presentations on the subject. In addition, I have traveled extensively over the years and seen first hand the increasing difficulties that traditional farmers face. I consider myself an advocate for vertical farming and will continue to promote the idea for as long as anyone will listen.

As the vertical farm industry matures over the next 10 to 20 years, I anticipate that governments will become more supportive of the concept and will establish funding opportunities for university-based research on the subject, as is now the case in Japan, and to a lesser extent in South Korea. The government of Singapore is fully behind such an approach, with the long-term goal of establishing sustainable in-country food security, safety, and sovereignty.

The more people who learn about the advantages of CEA, the more likely it is that CEA, in some form, will become a regular feature of every urban center.

As CEA evolves into a variety of systems for the mass production of commonly consumed vegetables, fruits, and herbs, more farmland can be allowed to revert to its original ecological function, such as hardwood forest. This in turn will allow the earth to fully function, once again, as our life support system. Intact terrestrial ecosystems filter our water naturally, and forests purify the air we breathe. Without agricultural runoff, the oceans can return to a pH that allows shellfish and coral reefs to thrive. All this is possible once we re-invent farming and move our food production centers close to where most of us choose to live: the city.

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Organic hydroponic vegetables in a vertical garden.

In a Word: Cooperation

Markus Demmel

At the Institute of Agricultural Engineering and Animal Husbandry of the Bavarian Research Center for Agriculture, I coordinate the activities in plant production engineering. The aim of our work is to identify the challenges and develop the contributions of agricultural engineering for sustainable plant production in Bavaria and define extension guidelines based on the outcomes of our applied research.

A major challenge that Germany, especially Bavaria, is facing today is the impact of climate change, which can already be observed. In our region, climate change means that arable farming will face more and heavier rain and more and longer dry periods, although the average annual precipitation may not change significantly. These changes will require improved soil management, with all operations optimized for the changing requirements.

Earlier research has shown that management strategies known for their positive effects on soil, such as mulching or no-till planting, cannot be simply copied to our region from other places in the world. Instead, they have to be adapted to our situation and integrated into our farming systems. For example, about 80% of the arable land in Bavaria is still plowed. The reasons for this are manifold and include agronomic, climatic, and social factors.

Strip tillage is an example of a process that has been successfully adapted in Bavaria. During the last few years, agricultural engineers and agronomists have successfully adapted strip tillage to arable systems with large amounts of residues and cover crops, and combined it with the application of liquid manure to avoid ammonia emissions while preserving the soil cover.

Further challenges we expect are based on projected resource limitations, especially phosphorus, which is predicted to become depleted within the next 35 years. Since we can't create more phosphorus, we have to close the nutrient cycle within agricultural enterprises and beyond. Agricultural enterprises export phosphorus and other important nutrients in the form of agricultural products. Recycling these nutrients back to the producer is possible; however, to meet this challenge, our research has to go beyond the borders of agriculture. Civil engineering, environmental engineering, and wastewater engineering will also be involved.

In general, to meet the challenges that we face in our attempt to feed the world in 2050, we must not look to a single machine, a single plant, a single nutrient, or a single discipline. We have to look at the production process as a whole, and multiple disciplines will have to cooperate. This cooperation will be the key to solving the problems that agriculture faces in Bavaria and around the world.

Specifically, to feed the world in 2050, we need more intensive cooperation both within and among scientific communities. This exchange has to take place horizontally among various organizations and disciplines and vertically among the levels of basic research, applied research, and practice. In both cases, we have to overcome long-standing traditions and resistances.

Because we all compete for funding, the organizations that provide funding need to create conditions that support and enforce cooperation. This has to start with the calls for research proposals and continue with breaking down the obstacles to cooperation among researchers in organizations, disciplines, and research levels.

To enable vertical cooperation, the practice of evaluating, ranking, and funding researchers and their institutions based solely on publication in peer-reviewed journals has to change. A university professor recently told me that he would very much like to work with me on a farming research project, but he simply can't. The work would not allow publication in a peer-reviewed journal, and working on a project without the chance of peer-reviewed publication is against the rules of his university!

I am confident that the knowledge, creativity, and imagination of agricultural engineers and researchers will be able to provide enough food for the world in 2050. However, to enable the necessary horizontal and vertical cooperation, the self-perception of researchers, the traditional barriers among various organizations and disciplines, and the methods of funding must change. To improve how agriculture works, we must first improve how we work.

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Top photo by Peggy Greb, courtesy of USDA-ARS.
Bottom photo by Hans Kirchmeier.

September strip tillage for sugar beets in an early cover crop of red clover.

Agricultural Technology Challenges for 2050

Josse De Baerdemaeker

We can start the discussion about feeding the growing world population by noting that the population increase will not be evenly spread across continents, nor will it occur in what are now the most productive areas of the world. We can also expect that the housing requirements for the growing population will be met by occupying some arable land. At the same time, it will be more difficult to bring new land into cultivation because of environmental and climate change concerns, as expressed in many recent studies. Meanwhile, the productivity of available agricultural land faces the challenges of soil erosion, compaction, and degradation, as well as the increasing unpredictability of weather and of water resources.

The development of agricultural technology and its deployment in the middle of this century will therefore be based on close cooperation between engineers, agronomists, crop breeders, soil scientists, and farmers. The outcome of this effort will be future production practices that both exploit and increase biodiversity. The technologies will be similar across the globe, but their local implementations will differ. Farmers will also work in close interaction with consumers and interest groups to obtain a license to produce. Traceability of production will mean not only "show us what you did" but also "tell us why you did it."

Crop breeding technology is making rapid progress in resistance to diseases, as well as in resistance to substances that can be used for chemical weed control. Additional breeding programs, using genetic modification or other techniques, will result in highly productive crops by greatly increasing photosynthetic efficiency, creating what some call "turbocharged" crops. These crops may be food or feed, or they may be feedstocks for energy production or green chemicals.

Automation in agricultural production will also be a key for sustainability. Different equipment sizes will be chosen based on the job, rather than on the relative size of the farm or field. Because soil conservation implies reducing soil compaction, tramlines with flexible attachments may be used for cultivating large areas. Another possibility is the use of swarms of lightweight, agile machines for planting, crop maintenance, and harvesting. These machines will have access to information on soil type, local microclimate, planting depth and density, and fertilizer treatments. Because the planting schedule will be matched with the treatment and harvest schedules, on-line record keeping will be standard practice. Spatio-temporal crop growth and development will be continuously monitored by satellite or UAVs. Small robots that continuously walk the fields and on-plant monitors will provide additional information on growth conditions and impending diseases, pests, and weeds. These observations will be compared to crop growth models so that corrective actions can be designed and implemented in real time.

New pest invasions will become more frequent due to global trade. Harmful pathogens that hide and thrive inside food plants must be detected and eliminated. As a result, sensor networks and spatio-temporal data analysis will be required for optimal crop production. The most important stress sensor is the plant itself, and it is possible to differentiate between different stressors. Breeders will succeed in incorporating gene expression that depends on the stressor and its severity. This may involve a slight change in mechanical or optical properties at different locations on the plant, or odors that are specific to a stressor. In a similar way, weed detection will be improved by incorporating optical characteristics that make weeds easily distinguishable from crop plants and that can be programmed so that volunteer plants (now weeds) are also detected. Using similar methods, weed resistance to chemicals can be detected, and mechanical, thermal, or laser-based weed removal can then proceed.

Selective harvesting of crops will be possible with small, agile, autonomous harvesters that are controlled on the basis of information obtained during the growth stage to selectively harvest individual plants with the desired level of maturity and quality.

It is unlikely that the same farmer will work the same fields every year. Farmers will specialize in certain crops and achieve crop rotations by exchanging land with other farmers. These crop rotations between farmers will require that accurate soil information, including drainage, water holding properties, and fertilizer inputs, is available in on-line databases. These databases can also include fertilizer or pesticide treatments, spatially variable growth data, and yields of previous crops so that the follow-up farmer can assess the suitability of the land for a subsequent crop and make appropriate decisions for efficient production. This production method will allow specialization of equipment and crop production without exhausting the soil or bankrupting the farmer.

Reduction of fossil fuel consumption for food production is a must, and energy crops are one possibility. Producing energy from non-food feedstocks will not limit food availability. The introduction of nitrogen-fixing plants, either in mixed cultures or by genetic modification, is another part of the solution. Phosphorous can be effectively recovered from waste streams. Crop breeding can improve energy extraction from residues, eliminating the growers' reliance on distant processing plants. Novel harvesting, storage, and processing technologies that limit food losses and food waste are already in place and available.

Given all these technologies, and the future technologies that are now in development, we can look forward to exciting cross-disciplinary activities that will eventually lead to sustainable production of food for all the people of the world. These technologies will contribute to enhanced biodiversity as well as to a flexible response to rapidly changing biotic and abiotic production conditions.

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Improving Agricultural Productivity in Developing Countries

Brian Boman and Jean Robert Estime

One of the 3,100 master farmers—a *paysan vulgarisateur* in Haitian Creole—who graduated under the Feed the Future West/WINNER project. These master farmers are primarily extension agents selected from candidates proposed by community-based organizations. They received six months of training, including four mandatory courses (agriculture, environment, small farm management, and family planning/nutrition) plus two elective courses (cereal production, vegetable production, introduction to mechanized agriculture, etc.). The photo was taken at the Bas Boen CRDD, one of the training and demonstration centers built as part of the project, located in the Cul de Sac plain just east of Port au Prince, Haiti.

Our experience includes working with agricultural producers and associations in developing countries in Eastern Europe, Central Asia, Africa, the Middle East, Mexico and Central America, Southeast Asia, South America, and the Caribbean. Each of these regions has its own set of challenges concerning food production. However, some issues are common to all developing countries, including low yields; improper post-harvest handling and storage; lack of access to long-term capital at reasonable rates; land ownership or allocation practices that result in uneconomic production units; degraded or non-existent infrastructure; lack of education on agricultural production practices; lack of good-quality seeds, fertilizers, pesticides, and equipment; lack of access to extension professionals who can demonstrate improved practices; little knowledge of markets and how to maximize returns; degraded or salinized water and soil; and, in many cases, government instability that makes investing in agriculture risky.

With all these challenges, it is important to realize that long-term food sustainability will not be achieved by subsistence farmers as they currently operate. Most of these farmers are so focused on short-term survival that they have no vision of the future and don't recognize the importance of soil stewardship, conservation, and good farming practices. Many lack the education and skills necessary to make informed production decisions and try new practices. So, one of the paths to increased food production in developing countries is to make subsistence farmers much more productive and profitable, so that they can become entrepreneurs through individual breakthroughs and improved collective organization. In other words, we must disseminate modern techniques and the best inputs to help smallholder farmers make a big quantitative and qualitative leap forward.

We must abandon the idea that—because we are working with poor farmers—we must promote low-cost, technically sub-par practices. Only 21st century technology applied to all aspects of agricultural production, commercialization, and processing will ensure long-term food security and financial sustainability for subsistence farmers.

The most challenging issue is to identify the farmers in each community who are open to progress and ready to take risks to change their traditional practices. Others will imitate these leaders when they see the production and income improvements. Most important, it is essential to foster mutually rewarding business relationships between smallholders, larger farmers, and agribusinesses at all phases of the agricultural value chains.

Successful adoption of vertical production and drip irrigation in a farmer-built hoop house in Haiti following training by the Feed the Future West/WINNER program.

The key question is how governments in developing countries can support and promote large-scale agricultural modernization among subsistence farmers that will lead to nationwide food security. First, governments must commit more resources to long-term investment in agriculture. This means funding to repair, operate, and maintain infrastructure such as irrigation and drainage systems, farm-to-market roads, transportation networks, and packing and processing facilities. Long-term agricultural loans, crop insurance, and disaster recovery programs should be instituted. Cooperatives to allow farmers to leverage their inputs and sell their outputs should be facilitated, and creating efficient and honest markets should be a priority. In addition, governments must protect and stimulate national production through legal and regulatory reforms that create an enabling environment, as well as facilitate business development, provide access to affordable credit, scale-up research and extension services, and strengthen the rule of law.

Farmers of all socioeconomic backgrounds are resistant to changing their practices. However, when farmers can see the results of improved soil preparation or new varieties, they are generally willing to consider new practices. With this in mind, it is essential to develop well-funded demonstration farms with trained personnel to expedite the transfer of new or improved technologies in developing countries. It is also important to identify and engage local farmers in the operation of these centers.

The demonstration farms and accompanying training that we've helped set up in Haiti as part of the USAID-funded Feed the Future West/WINNER project have already had a tremendous impact on smallholder farm income (www.feedthefuture.gov/country/haiti-0). Increases in production have been achieved by some 30,000 smallholders as a result of the training and demonstrations conducted by WINNER. Overall, bean yields increased 95%, from an average of 568 kg ha^{-1} in 2009 to 1200 kg ha^{-1} in 2012. Corn yields increased 486%, from an average of 708 kg ha^{-1} in 2009 to 4,150 kg ha^{-1} in 2012. Rice yields increased 139%, from 2,200 to 5,260 kg ha^{-1}, mainly due to the introduction of the system of rice intensification (SRI). Plantain yields increased from 13,000 to 20,310 kg ha^{-1}, an increase of 56%, primarily due to the introduction of double-row planting.

But the most striking innovation has been the introduction of small hoop houses with vertical agriculture for vegetables and flowers, which multiply farmer income more than 20-fold when well implemented. Thanks to the Greenhouse Revolution, smallholders in the mountains can build a hoop house in a few days and install drip irrigation systems that allow them to grow high-value crops throughout the year while using every drop of water.

Over the next few decades, there will be room for considerable increases in food production in developing countries. If local stakeholders and donors are committed for the long term to apply high-yielding technologies at a scale that will significantly change the behavior and performance of subsistence farmers, then remarkable results can be achieved.

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Photos by David Rochkind.

It's not a Matter of If, but How

Jacob Bolson

I work for John Deere's application equipment business—that is, sprayers—while supporting my wife's family farm in central Iowa. My role on the John Deere team is to focus on aftermarket business growth opportunities for sprayers that originate in our factories in Des Moines, Iowa; Horst, The Netherlands; and Catalao, Brazil.

As I thought about food production in the year 2050, I scanned some of recent newspaper headlines related to agriculture, for example: "$3.24 new crop corn at the local grain elevator" and "Livestock producers enjoying well deserved profits after years of financial challenges." The agriculture news also includes daily debates about biotechnology, environmental concerns, and new developments, such as "big data" and UAVs.

What is our path to feeding nine billion people by the year 2050? Looking back at food production in 1978, the amount of change that has occurred in the last 36 years is remarkable, but we need more than remarkable change to meet the challenges that are coming.

What do we need to do to support farmers in feeding nine billion mouths while working through the coming changes and their impacts on farm management? Looking ahead, we are entering an era of increasingly stringent environmental regulation, significant skilled labor shortages, and exponential growth in the tools that farmers will have access to for raising and managing their crops.

Environmental regulations

Environmental regulation may be the most contested issue in agriculture. As I write these words, a rally is being staged here in Des Moines, Iowa, for increased government action on ensuring water quality and further regulations on agriculture. The public is concerned about environmental issues, and agriculture is facing increased scrutiny for its environmental stewardship. Rekha Basu, a columnist for our local paper, *The Des Moines Register*, recently wrote an editorial titled "We can't let agriculture destroy our environment."

Farmers need our help to improve their environmental stewardship beyond their current initiatives, and they need access to economically feasible technology to quantify their environmental impacts. Much of this technology already exists, and more is coming. For example, by 2050, I predict that all subsurface drainage systems will be actively monitored, controlled, and filtered by intelligent water management and biological control tools. Because of advances in subsurface irrigation technology, millions of acres will no longer rely solely on surface-applied crop fertigation. Strategies for determining nutrient levels applied by both surface and subsurface systems will change radically thanks to multi-depth soil sensor networks. These technologies will be scalable—and affordable—for a 10,000 acre operation in western Illinois as well as for a smallholder in sub-Saharan Africa.

Skilled labor shortages

A shortage of skilled labor is already affecting agriculture on a global basis. The changing rural versus urban population demographic will drive farmers to rely increasingly on automation technology. Skilled labor will always have a place in production agriculture, particularly for high-value crops and for tasks that are beyond the abilities of a machine. However, the skilled labor shortage also carries over to the agribusiness supply chain, ranging from equipment dealerships to agricultural service providers. We must have more collaborative efforts by industry, agricultural organizations, and government to encourage rural population placement and to attract ambitious young people to the agricultural sector.

Farm management tools

UAVs, big data, biotechnology—producers are encountering these new terms, and many others, much more often. This new, technical vocabulary for farming brings a few thoughts to mind:

I'm not sure when "data" was transformed to "big data," but searching on "big data" returns 15.9 million hits on Google. Even though we now have big data, data management will still be a challenge in 2050 because there will be so much more data to manage. What is the economic value of all these data? Many farmers who started collecting yield monitor data in 1992 still struggle with using those data for strategic planning. Gathering big data is not enough. We must provide solutions that allow farmers to extract value from data.

As we provide farmers with continued improvements in crop production through technology solutions—such as UAVs, sensor networks, and other complex devices—what does the service and support model look like? Is the service technician who's tasked with supporting a 600 horsepower tractor the same technician who supports a fleet of UAVs? What does the customer support strategy look like for a subsurface biological water filtration system? Deploying useful technology is not enough. We must also provide a service and support infrastructure to keep that technology running.

Biotechnology in North American crop production has nearly 20 years of field experience, and the debate about biotechnology is as strong as ever. Public concern about biotechnology continues, while—within the agricultural sector—biotechnology is seen as a useful tool for feeding the future population. We must recognize that consumers want diverse choices, which has been demonstrated by the growing acceptance of biotechnology, but also by the growth in specialty markets, such as organic farming.

Where will we be in 2050? Even more diversified than we are in 2014, and the debate will continue. However, for the sake of nine billion people—and through engineering advances in energy, soil, air, water, food, and fiber—we will meet the challenge.

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Toward Robotic Agriculture

Simon Blackmore, CEng

Mechanized agriculture uses massive amounts of energy in myriad forms, from the energy associated with chemical pesticides and fertilizers, to the tractors and implements and the fuel needed to power them. This energy is often wasted when it goes off-target. It's also expensive and will become more so in the future. Smart machines should use the minimum amount of energy to turn the natural environment into useful agriculture, thus saving energy and reducing costs.

Let me give an example of how the current system uses too much energy. I estimate that up to 90% of the energy going into traditional cultivation is needed to repair the damage caused by the machines themselves. Each horizontal kilonewton of draft requires a vertical kilonewton for traction, which causes soil compaction. Therefore, without vehicle trafficking, 60% to 70% of the tillage energy would not be needed. If we retain just the 20% to 30% that is used for occasional deep loosening of the soil, we can see that there should be significant energy savings by not compacting the soil in the first place. In other words, if we can find a way to avoid dragging metal through the soil, we can nullify the compaction problem.

Currently, tractors, combines, and other agricultural machines are increasing in size due to economies of scale. However, as the machines get bigger, the opportunity to work the fields gets smaller due to the fragile structure of the soil, especially when wet. This cycle can only be broken by making the machines significantly lighter so as not to damage the soil, and thus expand the time available for field operations.

Most new large tractors have autosteer systems that allow much more accurate positioning to avoid overlap and skip in field treatments. That improvement saves 10% to 15% of the time and operating costs. In addition, many tractors now use a CAN bus for internal system management and an ISOBUS to communicate with attached implements. Instead of the tractor controlling the implement, the implement controls the tractor.

Telemetry is another innovation that allows new levels of management. New combine harvesters are *x*-by-wire, so a lot of data about the machine is digitally available. Some models can even transmit this information back to the factory for analysis. If the machine starts to operate outside of normal tolerances, say a belt starts to slip, the driver can be alerted via mobile phone before the problem becomes a disaster.

"Norman," a seeding robot designed to put seed in the ground even at field capacity (seeder to be developed this year).

There are many other examples like this. So how do we take advantage of these new technologies? One way is to continue making incremental improvements to the current system. An alternative approach would be to start with a whole new paradigm.

We know that farmers today have conflicting pressures—new legislation, environmental regulations, and commodity price fluctuations, to name a few. All of these pressures push farmers toward more efficient production. Combining these pressures with the opportunities presented by new technologies can lead to a new mechanization system that addresses all the concerns—environment, economics, and energy efficiency—in a new way. Such a system would also be based on plant needs, using precision agriculture to address the temporal and spatial variability of crops.

Can we develop a new system of agricultural mechanization that can assess crop variability in real time and use only the minimum amount of energy required to support crop development? The answer is a qualified yes. We have not yet developed all the technologies needed, but many have been prototyped, and we can start to visualize how such a system would look. My vision for the future is one where small smart machines move around the field independently, establishing, tending, and selectively harvesting the crops. Call it agricultural robotics.

Ten years ago, I developed an autonomous tractor that could mechanically remove weeds, thus achieving 100% chemical reduction. Back then, the tractor was too big and used more energy than was needed. More recently, one of my former doctoral students has developed a laser weeding system that uses machine vision to recognize the species, biomass, leaf area, and position of the meristem (growing point). A miniature spray boom only a few centimeters wide can then apply a microdot of herbicide directly onto the weed, thus saving 99.9% of the spray. Alternatively, a steerable 5 W laser can heat the meristem until the cells rupture and the weed becomes dormant. These devices could be carried on a mobile robot no bigger than an office desk, working around the clock, without damaging the soil or crop.

Another application is selective harvesting. Currently, many vegetable crops are harvested by hand, which is expensive even with the cheapest labor. In addition, up to 60% of the harvested crop is not saleable to supermarkets because it does not have the desired quality attributes—too small, too large, incorrect cutting, blemishes, etc. Selective harvesting involves using a robot to assess all of the quality attributes and only harvest the produce that has ideal saleable characteristics. If some plants are too small, they can be left until they grow to the correct size. By knowing the position, size, and expected growth rate, we can schedule an accurate second or even third harvest in the field.

Looking at all the operations needed to establish, care for, and harvest crops, while minimizing inputs, we can see how such a mechanization system could evolve over time and adapt to changing circumstances. That adaptability is the key. We must stop defining what we do now by the way we have done it in the past, and instead look at the fundamental problem. Only then can we create new ways of meeting the economic and environmental requirements of crop production—and do a better job of caring for the planet.

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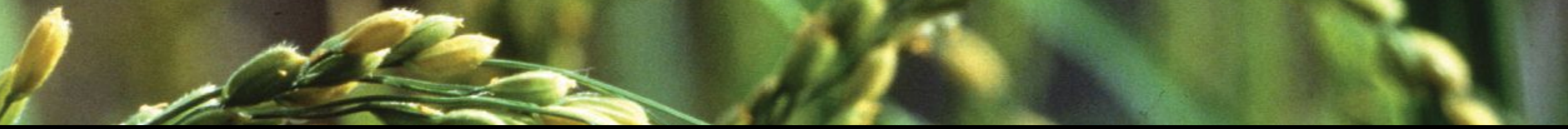

Precision Agricultural and International Development

Sreekala Bajwa

Rice farmers using modern technology.

As an academician, my primary involvement in food production is through research and education. To feed the world in 2050, our research and educational efforts should focus on increasing food production with limited resources under the changing climate, minimizing food losses and wastage, and addressing poverty and policy issues. Precision agriculture is critical for increasing food production with limited water, energy and land resources, and for climate adaptation and mitigation. However, international development will a play key role in increasing the efficiency of agricultural production by scaling and adapting agriculture technologies to meet the local needs across the world.

Precision Agriculture

Precision agriculture is the application of engineering, agricultural, information, and communication technologies to agriculture to increase production efficiency and reduce risk. It involves gathering data relevant to agricultural production, mining information from the data, and making informed decisions to improve production efficiency and to lower risk by managing fields for the conditions that already exist or are anticipated. Such decisions may include what, when, where, and how much of various inputs such as seeds and crops, tillage, water, fertilizer, pesticides, other chemicals, and other cultivation practices would be optimal. Precision agriculture uses information on weather, soil, topography, field history, crop genetics, commodity markets, and long-term climate trends to identify short-term and long-term practices to produce nutritious and healthy food with limited resources.

In regions with large-scale, highly mechanized, and technologically advanced agriculture, precision agriculture helps to customize management practices by spatially varying input applications to match the specific needs of different areas within a field. This strategy reduces input losses, increases input efficiency, and results in major economic and environmental benefits. Where farm sizes are small and agriculture is less mechanized, precision agriculture can help to develop the best management practices for individual fields or groups of fields. For example, knowledge of soil type and fertility can be used to develop fertilizer application regimes. Soil, terrain, and rainfall data can be used to develop decisions on planting rate, planting and harvesting times, and fertilizer application strategies. Knowledge of climate patterns can help in identifying the best crops or varieties to plant, and whether or not to invest in an irrigation system.

Information and communication technology (ICT) such as agricultural informatics for converting data to decisions is a critical part of precision agriculture. In the past two decades, many technologies have been developed to gather data on crops, soils, terrain and weather, process data into information and decisions, and communicate this information/decisions to end users. The farm machinery available in developed countries today has the capability to read maps and integrate crop sensors to spatially vary input applications to match crop needs. Many of these machines can also relay information back to decision makers using telemetry. Irrigation systems have the ability to integrate crop water sensors to vary water application. Cell phones can be used to fly an unmanned aerial vehicle over a field to collect data, or communicate important information to farmers. Major seed companies have been developing smart planting systems that will select the crop variety and planting rate on-the-go to suit the needs of a specific field. ICT has improved agriculture globally. A good example is the success of cell phone applications in African and Indian agriculture.

International Development

While very efficient agricultural technologies are available in some parts of the world, many other regions are still using inefficient practices and labor-intensive manually powered tools. The agricultural research and education needs of developing countries that we repeatedly hear include development of farm equipment and irrigation systems suitable for these regions to enhance their production efficiency, production practices to conserve and protect resources, preparation for uncertain and extreme weather events, storage and transportation systems that reduce food spoilage, and processing facilities that convert perishable commodities into products with long shelf life.

International development through global collaboration and translational research is essential to addressing the global food challenge. Scaling precision agricultural technologies to suit the needs of the developing world is guaranteed to increase food production efficiency. I propose that we, the researchers and educators who work in food production and processing, devote some of our time to international development, and that we involve our students in these endeavors. International development based on precision agriculture will protect resources, contribute to mitigating climate change by reducing the carbon, nitrogen, and water footprints of agriculture, adapt agriculture to new climate realities, and increase production efficiency.

Conclusion

Collaborative research to scale precision agricultural technologies for different regions of the world and international development in all areas of agriculture are vital for food security in the future. We should also focus on educating the next generation on the food and resource realities of the world we live in, and instill a passion for addressing the needs of our fellow human beings.

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Managing the Farm Microbial Ecosystem

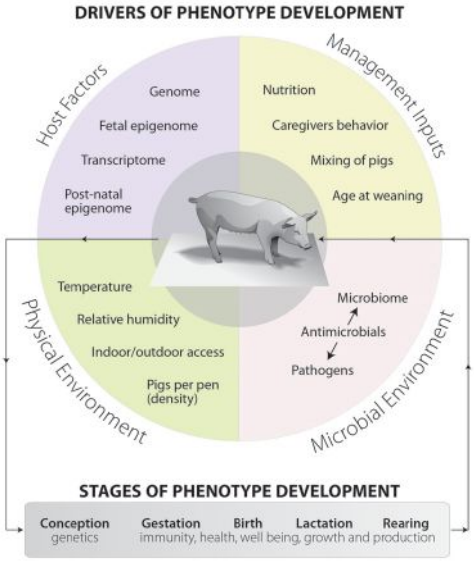
Brian Aldridge

My parents gave me an appreciation of food production through their stewardship of the land, crops, and animals that have been their source of income and contentment for 70 years. My exposure to livestock production in the beautiful Wiltshire countryside of southern England was the foundation for my career in food animal health and production. As a veterinarian, I have contributed to an abundant, safe, and healthy food supply through my work as a clinician, researcher, and educator.

In the 1960s, when I was young, there were few concerns about food production in the U.K. Livestock production was based on low-technology rearing systems with relatively low levels of infectious disease. Since then, the U.S. livestock industry has developed a high fixed cost, low operating cost, low margin production system based on animal confinement and the widespread use of antibiotics. Because of its ability to produce animal-based food at a low cost, this production model has been adopted around the world, particularly in emerging economies seeking to meet their own protein needs. As a result, the sustainability of global animal-source food production is entirely dependent on the constraint of infectious disease, and therefore completely reliant on antibiotics.

Due to public health concerns about antimicrobial-resistant infectious agents, the U.S. Food and Drug Administration (FDA), and equivalent agencies in Europe, are now implementing voluntary plans with industry to phase out the use of certain antibiotics in food animals. Inevitably, widespread antimicrobial use will disappear from food production systems due to public demand and policy changes. The industry will then be faced with the staggering challenge of maintaining efficient production without the freedom to employ antibiotics to manage infectious disease. When this post-antibiotic era becomes a reality, it will present a great risk to the security and sustainability of global food production through a reduction in production efficiency. It also means that livestock will more likely be managed in ways that further burden our environmental resources.

So how can we modify our approach to livestock management, and refashion our antimicrobial practices, in a way that preserves the security and safety of our food supply? Antimicrobial use in livestock systems is almost exclusively directed at removing or preventing disease by specific pathogens. This focus on infectious disease control by minimizing contact with or destroying bacteria is based on the successful reductions in morbidity and mortality achieved with antimicrobial practices over the past century. While this has clearly been a successful strategy, it has also led to a pathogen-centric view of microbes. This demonization of microbes has slowed somewhat in recent years due to the many studies showing that the microbiome, the community of beneficial commensal microbes, coexists in a symbiotic relationship with its host, enhancing the host's health and productivity by preventing the expansion and colonization of harmful microbes.



Overview of the food production ecosystem.

Microbial colonization of host mucosal surfaces begins early in life, following the acquisition of pioneer organisms from the mother. There is considerable variation in the composition of the microbiota during the first years of life, but the most desirable trajectory is toward richness and diversity. The drivers of the microbiome fall into broad categories related to the host (e.g., genome and epigenome), the environment (e.g., temperature and humidity), and system inputs (e.g., nutrition, housing, and hygiene). This process is strongly influenced by management factors (including antimicrobials), and it is tightly linked to the host's immune system.

It is evident that a healthy microbiota serves a vital role in establishing immune competence and, conversely, in precipitating incompetence and dysfunction when disturbed. There is also compelling evidence that antimicrobials exert an effect beyond pathogen eradication by influencing the ecology of the microbiome, and subsequently altering the host's metabolism, as well as the development of antimicrobial resistance. These effects of antimicrobials on the host microbiota likely persist for life.

Our use of antimicrobials in animal health management could be transformed by a broader understanding of the beneficial role of microbes in livestock health. This could begin with a new appreciation of livestock-based food production systems as complex, multi-organism ecosystems, the efficiency and productivity of which depend on potentially fragile interactions between different ecological communities—animals, microbes, and people—and their environments. This change in mindset, away from the idea of microbes as a primary cause of poor health and instead seeing microbial communities as a reflection of our success in ecosystem management, would transform our current approach to enhancing the efficiency of livestock-based food production.

The host organisms—ourselves and the animals we raise—are microbial ecosystems within the greater ecosystem of the production system. We need to understand the impact of various management practices and environmental designs on host-microbe interactions. Only by understanding the ecology of the food production system can we identify and design sustainable strategies for optimizing livestock health and productivity in particular, strategies that are not dependent on the widespread use of antibiotics.

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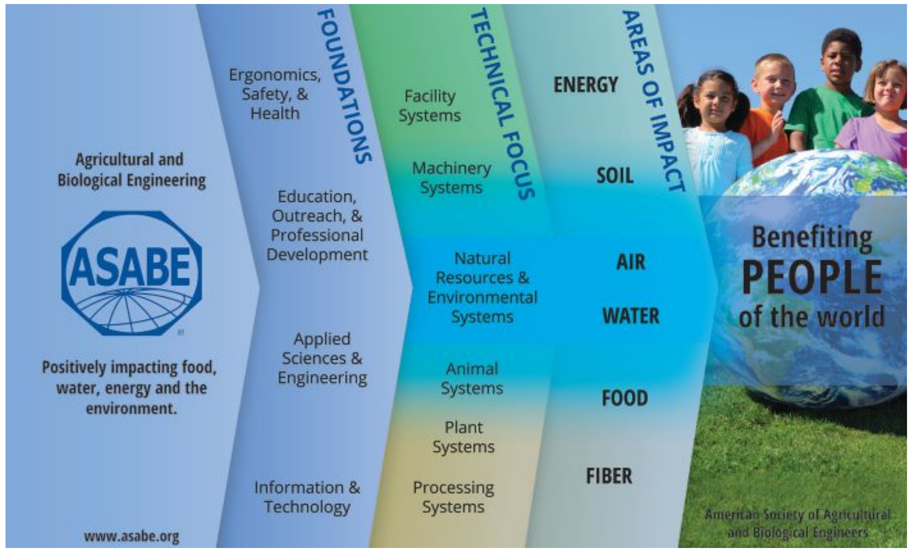
We Will Feed the World in 2050

Lalit Verma

Agricultural and biological engineers (ABEs) will be critically important in feeding an additional three billion people by 2050. Our profession's past contributions to safe, affordable, and abundant food are proof of that.



Ensuring food security for the projected global population is a daunting challenge. However, a bright spot is that major contributions toward food security can be achieved without increasing production—for example, by reducing post-harvest losses. My confidence stems from my international experience as a post-harvest agricultural engineer.

In fact, because we need to produce more food with fewer inputs per unit of land, and then deliver this food to the people who need it most, production increases—by themselves—won't be enough. In addition to reducing post-harvest losses, we must also increase the efficiency of our production systems. We have started to do this by combining our engineering expertise—including precision farming, micro-irrigation, sensor networks, robotics, and other technologies—with expertise from other professionals, including agronomists, soil scientists, geneticists, entomologists, agricultural economists, and many others.

To do the most good, these collaborations need to be global, to match our combined expertise with local needs around the world. This is especially important for the developing world, as the large-scale strategies that work in developed countries must be adapted, using technologies that are appropriate for different cultures and different climates with even greater resource constraints. Fortunately, our recent successful collaborations with scientists in other fields have so far demonstrated that we can solve the complex problems of food production with constrained resources of land, water, and energy.

At the 2014 ASABE/CSBE Annual International Meeting in Montreal, we mapped out the global challenges and opportunities for ABEs as part of the Global Engagement Day activities. To further our ABE Global Initiative, we are developing a strategic position paper that identifies ABEs' importance and responsibility in sustainably feeding the world in 2050.

This paper outlines the challenges before us, highlights the specific needs of three "security" themes (food security, energy security, and water security) in the context of sustainability and climate change, and specifies how ASABE, its members, and its partners will address the grand challenges. Our strategy is expressed in the following goals:

1. Improve food productivity.
2. Reduce food losses and waste.
3. Enhance energy conservation and efficiency.
4. Develop adaptable renewable energy systems.
5. Improve water availability, conservation, and efficient use.
6. Provide clean water for multiple uses (human consumption, agriculture, recreation, ecosystem services, biodiversity, etc.).

These goals may sound familiar to you—in a way, they summarize the long-standing efforts of the ABE profession. We can be proud of what we've accomplished, so our strategy also involves showing the world who we are, what we do, and how our work has improved the quality of life for everyone. In particular, we must ensure that policy-makers are aware of the proven strengths and expertise of our profession.

Despite the challenges facing us, I believe that our future is bright, that all problems have solutions, and that our profession will be profoundly important in the global effort to feed the world in 2050.

ASABE Fellow and Past President Lalit Verma, Professor and Head, Department of Biological and Agricultural Engineering, University of Arkansas, Fayetteville, USA; lverma@uark.edu.

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