Exploring Sustainable Solutions for Increasing Global Food Supplies: Report of a Workshop

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Exploring Sustainable Solutions for Increasing Global Food Supplies

Report of a Workshop

Committee on Food Security for All as a Sustainability Challenge

Science and Technology for Sustainability Program

Policy and Global Affairs

NATIONAL RESEARCH COUNCIL
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This summary report and the workshop on which it was based were supported by the Bill and Melinda Gates Foundation, the Syngenta Foundation for Sustainable Agriculture, the U.S. Department of Agriculture, and the George and Cynthia Mitchell Endowment for Sustainability Science. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

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PREFACE AND ACKNOWLEDGMENTS

In May 2011, the National Research Council's Science and Technology for Sustainability Program convened the second of two workshops to address the sustainability challenges associated with food security for all—*Exploring Sustainable Solutions for Increasing Global Food Supplies.* The first workshop in this series—*Measuring Food Insecurity and Assessing the Sustainability of Global Food Systems*—was held in February 2011.

Estimates made by the United Nations predict that the world population will increase to 9.3 billion by 2050[1] and 70 percent more food will be required, posing a global sustainability challenge. The workshop was designed to address a set of critical questions:

- Can the world feed future generations?
- Can it do it sustainably?
- At what food price?
- What action is needed?
- Who should take the action?

Workshop objectives included identifying the major challenges and opportunities for change associated with achieving sustainable food security and identifying needed policy, science, and governance interventions.

While sustainable food security for all depends both on sustainable food supplies and assuring access to food, this workshop focused specifically on assuring the availability of adequate food supplies. Workshop participants were asked to examine long term natural resource constraints, specifically water, land and forests, soils, biodiversity and fisheries. They were also expected to discuss the role of knowledge, technology, modern production practices, and infrastructure in supporting expanded agricultural production and the significant risks to future productivity due to changes in the climate.

Several themes were elucidated during the workshop discussions. For example, although food supplies must be expanded to meet increasing demand arising from population growth and rising incomes, this increase in food supplies could—but may not—be done sustainably. While there was no agreement on how much future food prices would change, continued price volatility is expected. Most participants noted that the increase in production could come from more efficient use of land, water and labor. Sustainable intensification--increasing productivity without damaging the productive

[1] New UN population estimates (for 2010) were released just at the time of our workshop. These new estimates suggested that by the end of the century the global population could reach 10.1 billion and 9.3 billion by 2050. See World Population Prospects 2010. Available at http://esa.un.org/unpd/wpp/Other-Information/Press_Release_WPP2010.pdf. Accessed on October 1, 2011.

capacity of natural resources—is likely to be far more important, according to many participants, than the expansion of land devoted to agriculture. As much as 70 to 85 percent of the needed increase in production is likely to come from intensification. The remaining production increases may come from expanding land use sometime into areas poorly suited for agriculture, with serious environmental consequences. Some participants noted that additional research is warranted in order to reduce yield gaps and lift yield ceilings.

Many workshop participants stressed the importance of farm-level intensification and improvements in soil quality and fertility. Lower levels of soil fertility are a particular problem in Sub-Saharan Africa, where soils have been severely mined over time. It is also important to recognize and manage critical ecosystem services and the need to internalize ecological costs. Many participants noted that such costs, as well as benefits, should be factored into prices to assure sustainable food supplies.

Most workshop participants recognized the potential value of organic farming systems in reducing or avoiding continued natural resource degradation. However, adhering to the organic farming practices as defined in the United States and EU and "natural" systems alone cannot provide the needed productivity increases. And if pursued on a scale needed to meet today's demand, such practices would have significant environmental ramifications. Furthermore, organic production methods may result in larger emission of greenhouse gases. Most participants thought that farmers should consider using all scientifically viable methods, including GMOs (genetically modified organisms). Most participants stressed the need for investments in public goods, especially rural infrastructure (e.g., roads that would support expanding) and more efficient supply chains, and they also emphasized the importance of securing property rights for family farms. The private sector was seen by many to have a critical role in providing tools, new technologies and investments in the agricultural sector.

There was considerable discussion about the importance of reducing post harvest wastes and losses, estimated to be as high as 30-40 percent of production, as a strategy to sustainably expand food supplies. A few participants suggested a number of ways to reduce these losses, noting that opportunities will vary by crop and by location.

Participants also stressed the importance of understanding and adapting to climate change. Many noted that the effects of climate change are already being seen, with significant warming in many regions and changes in precipitation making it more difficult to increase productivity, especially for key food crops. Recent weather and agricultural production fluctuations illustrate the impact of climate change.

Finally, some of the major factors identified by workshop participants that are likely to constrain the expansion of food supplies include the low priority given to agriculture by many developing country governments; inadequate international financial commitments to agriculture and agricultural research; institutional and infrastructure barriers to action by the private sector, including small holders; continued natural resource degradation; and many location specific challenges. Throughout the report, these themes are expanded upon.

This report has been prepared by the committee as a factual summary of what occurred at the workshop, and the statements made do not necessarily represent positions

of the workshop participants as a whole, the Science and Technology for Sustainability Program, or the National Academies.

The workshop and report could not have come together without the help of many dedicated staff members. Pat Koshel directed the project and coordinated the report. Emi Kameyama, Jennifer Saunders and Dylan Richmond provided invaluable support and assistance with our workshop and in preparing the final report.

This report is the result of substantial effort and collaboration among several organizations and individuals. We wish to extend a sincere thanks to each member of the planning committee for his/her contributions in scoping, developing, and carrying out this project.

The project would not have been possible without financial support from the Bill and Melinda Gates Foundation, the Syngenta Foundation for Sustainable Agriculture, and the U.S. Department of Agriculture. It also benefitted from the National Academies' internal support, provided by the George and Cynthia Mitchell Endowment for Sustainability Science.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Academies' Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for quality and objectivity. The review comments and draft manuscript remain confidential to protect the integrity of the process.

I wish to thank the following individuals for their review of this report: William Easterling, The Pennsylvania State University; Keith Fuglie, U.S. Department of Agriculture; Brian Greenberg, InterAction; George Hornberger, Vanderbilt University; Rattan Lal, The Ohio State University; and Sara Scherr, EcoAgriculture Partners.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the content of the report, nor did they see the final draft before its release. The review of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the author and the institution.

Per Pinstrup-Andersen, *Chair*
Committee on a Study of
Food Security for All as
A Sustainability Challenge

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1

INTRODUCTION AND OVERVIEW

The National Research Council's Science and Technology for Sustainability Program convened the second of two workshops addressing the sustainability challenges associated with food security for all on May 2-4 in the Venable LLC Conference Center, Washington, DC. The second workshop was titled "Exploring Sustainable Solutions for Increasing Global Food Supplies." Individual and household food security depends on access to the food needed to meet food and nutritional needs, a condition strongly related to household income. Food availability is necessary, but not sufficient, for achieving food security. However, availability of sufficient food for current and future generations is critical and must be based on sustainable methods of production and distribution, that is, using available resources in such a way that their availability for production and distribution in the future is not compromised or precluded. Recent and current debate surrounding recent food price volatility and the impact of climate change on the future food supplies makes the topic very timely and important.

Organized by a committee of experts appointed by the National Research Council, the second workshop involved a diverse set of participants: researchers, analysts, academics, and development leaders in a wide range of fields--food production, resource management, environmental conservation, climate, and others. While keeping in mind the critical importance of access to food, this workshop focused on the question of sustainable food availability and the related natural resource constraints and policies. The overall objective was to identify (i) the major barriers to expanding food production to meet future food demand without damaging the future productive capacity and (ii) policy, technology and governance interventions that could reduce these barriers and promote sustainable food availability as a basic pillar of sustainable food security.

WORKSHOP STRUCTURE

This workshop was built on the discussions at the first workshop held in February 2011, in which expert participants explored the availability and quality of metrics that helped us understand the concept of "sustainable food security." On the theory that "you can't manage what you can't measure," consideration during the first workshop was given to the metrics of: poverty, undernutrition or "hunger," malnutrition, farm productivity, natural resource productivity (land, water, soil quality, etc.), and food supply chain efficiencies and losses. It was clear that there were different ways of understanding and measuring these concepts and relating them to each other (e.g., household poverty and children's heights) in meaningful ways. The use of different geographic scales was particularly striking, as relevant data on production and productivity, for example, related variously to households, fields, farm, landscapes, river basins, nations, regions, or continents. By being "spatially explicit," it was believed that data and information relevant at smaller scales could also be meaningfully aggregated to meso- and macro-scales. Overall, however, experts in workshop one stated:

- The quality of metrics is not as good as it needs to be for accurately understanding, monitoring, or predicting food security and the sustainability of food production processes given natural resource conditions, policies, and market incentives.
- Suites of metrics/indicators are needed to understand the phenomena associated with sustainable food security (both availability of food and access of poor populations to it), although even existing suites of metrics are rarely integrated adequately for decision makers today.
- There are few integrated sets of relevant data that are widely accessible and that allow analysts to work at sufficiently broad scales as well as at more local (including household) scales.

The first day of the second workshop opened with a recap of some ideas presented at workshop one, reflecting the availability and quality of data indicators and projections of both poverty/food security and resource use trends as they are currently understood, while also framing the potential of various factors to pose new opportunities, risks and vulnerabilities that would affect trends going forward. These presentations enabled participants at workshop two to see what the existing evidence tells us regarding the magnitude of the problems and challenges and opportunities for their solutions. Subsequent sessions on day one of workshop two dug more deeply into the trends associated with natural resources that are believed to pose hard constraints to food supply and availability. The second day of this second workshop explored several of the policy, market, and governance approaches currently thought to be needed to resolve the constraints posed by natural resources to food availability at various scales: global, regional, and local. The third day engaged participants in consideration of what changes (in public policy and regulatory institutions, markets and other economic institutions dominated by the private sector, and social and cultural institutions) would be needed to raise the probabilities for ensuring that food availabilities in 2050 respond to global food demands and the nutritional needs of more than 9 billion people.

The organizers of the workshop recognize that the content of the workshop and this summary report leave out many important topics and perspectives associated with sustainable food supplies and the related natural resource constraints and policies. However, the time constraints of a two and a half day workshop forced the planning committee to limit the number of topics that could usefully be examined. One important topic that the workshop was to have addressed was the complex links between energy and agricultural productivity. However, due to unforeseen circumstances the speaker for this session was unable to attend the workshop. In addition, most participants focused on the production of the three dominant staple crops rather than a broader range of food crops. Hopefully, the energy-agriculture nexus as well as other important topics that are not included can be examined in other workshops or future meetings.

ORGANIZATION OF THE REPORT

This report, like the other report included in this volume, is limited in scope to the presentations, workshop discussions and background documents distributed to the participants in preparation for the workshop. The report does not necessarily reflect the views of the committee or the participants as a group. This chapter includes a summary of the presentation by the committee chair, Per Pinstrup-Andersen, providing a contextual framework for the workshop.

Chapter 2 includes summaries of a set of presentations examining the challenges in and opportunities for achieving sustainable food security, including an overview of current and expected future food and nutrition security. It also includes descriptions of key natural resource constraints and the role of climate change. Chapter 3 summarizes various approaches to achieving sustainable food supplies, including sustainable intensification, reducing yield gaps, addressing waste in the food chain, and the role of global public goods. Chapter 4 focuses on the political, economic, and institutional opportunities and barriers, and the final chapter discusses options for moving forward.

CONTEXTUAL FRAMEWORK FOR WORKSHOP 2[2]

Per Pinstrup-Andersen opened the meeting by asking a set of questions:

- Can the world feed future generations?
- Can it do so sustainably?
- At what food price?
- At what price volatility?
- Will everybody have access?
- What action is needed?
- Action by whom?

Pinstrup-Andersen answered the first two questions by saying that the world can feed future generations and--with appropriate action--can do it sustainably. This meeting will focus on sustainable food supplies, which is just one part of the food security equation (Figure 1-1). He noted that adequate food supplies are necessary but not sufficient for assuring food security for all. Who will have access to food depends on many factors including prices and incomes. Furthermore, household behavior, intra-household decision making processes and gender-specific time allocation are important components of the access issue that will not be considered in this supply-focused workshop. In addition, there are several non-food factors that influence food security, such as health, access to clean drinking water and good sanitation.

[2] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Pinstrup-Andersen (May 2, 2011).

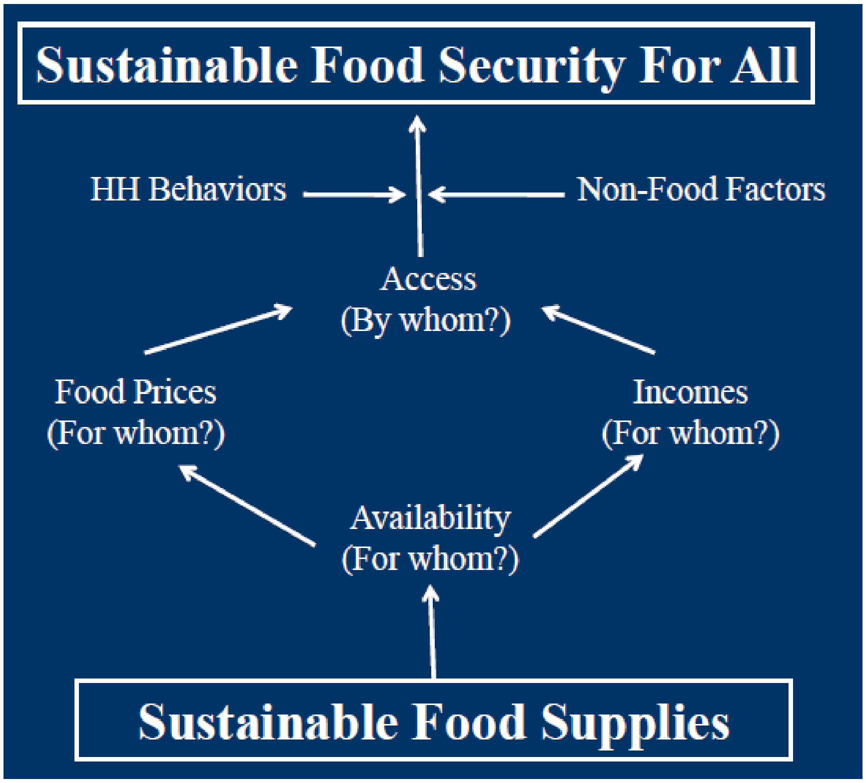

FIGURE 1-1 The workshop focus.
SOURCE: Presentation by Per Pinstrup-Andersen, Cornell University, May 2, 2011.

The workshop will focus on three elements critical to assuring long term sustainable food supplies: 1) barriers to sustainable food supplies, 2) approaches and action, and 3) incentives and limitations to action. Among the major barriers to sustainable food supplies are natural resource constraints--water, land, forest, soil, biodiversity and energy—and human-made resources--knowledge, technology, and infrastructure--as well as climate change.

The discussion on approaches and action will include examining R&D to reduce yield gaps and raise yield ceiling, farm level intensification and ecosystem management. Speakers will also discuss ways to improve value chains, reduce wastes and losses, and improve energy efficiency and enhance private investments in land.

The final workshop segments will examine some of the incentives and limitations to action, looking at the specific roles of the public sector, the private sector and civil society. For example, what kind of public goods need to be in place for the private sector to operate?

The intent of the workshop is not to answer all the questions noted above but to provide input to the debate about what the answers are. Per Pinstrup-Andersen noted that the debate about food security currently tends to the extremes with arguments such as "The world is running out of food," "Billions of people will starve to death," "We are losing our most critical natural resources," etc. This workshop should aim to provide evidence to enlighten the debate and support evidence-based decision making.

2

ACHIEVING SUSTAINABLE FOOD SECURITY: CHALLENGES AND OPPORTUNITIES

The first segment of the workshop focused on the challenges and opportunities for achieving sustainable food security. The session began with a summary from workshop one, examining the methodologies in use to measure food and nutritional security as well as to describe key natural resources essential for assuring the sustainability of global agricultural production. Subsequent speakers talked about the need for new agricultural paradigms; trends in agricultural productivity; and key natural resource constraints, including water, land and forests, biodiversity, and soils. There was also a session examining the likely impact of climate change on future food production and related risks and vulnerabilities. Each session was followed by a brief question and answer period.

CURRENT AND EXPECTED FUTURE FOOD AND NUTRITION SECURITY[3]

Hartwig de Haen, University of Göttingen

Summary Points from Workshop One

The first National Academies workshop ("Measuring Food Insecurity and Assessing the Sustainability of Global Food Systems") discussed the various types of methodology currently in use to measure indicators of food and nutrition security. Most participants noted that the current methods do not provide fully satisfactory indicators. They often differ considerably with regard to magnitude, trends and geographical distribution of hunger in the world. de Haen noted that specific proposals were suggested for improvements of all three key methods, the Undernourishment indicator based on Food Balance Sheets (FBS), household consumption surveys and anthropometry.

Enough Is Known to Call for Urgent Action against Hunger

Although we may not know the numbers of food insecure and malnourished with a high degree of accuracy, it appears safe to characterize the current state of food and nutrition insecurity as follows:

- Many developing countries are currently experiencing a **nutrition transition.** Lifestyles are becoming more urban and sedentary, with foods and drinks being more energy-dense and diets containing more processed foods, sugars, fats and animal products (Pinstrup-Andersen,

[3] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Hartwig de Haen (May 2, 2011).

2010). The result is a triple burden of malnutrition: one part of the population is still undernourished; many also suffer from deficits of specific nutrients, in particular micronutrients; and others are overweight.

- **Close to a billion people are chronically undernourished**. While subject to possible estimation errors, the FAO (Food and Agriculture Organization of the United Nations) indicator of 850 million undernourished persons in 2005/2007 seems to be a realistic order of magnitude. First, the estimate is still lower than the number of absolutely poor (people living on less than $1.25 per day), which the World Bank estimated at 1.4 billion in 2005 (Ravallion, 2011). Secondly, FAO's estimates are compiled using rather low rates of intra-national inequality of food availability. Many household consumption surveys show significantly higher coefficients of variation.
- **More than 2 billion people are suffering from various forms of micronutrient deficiency**. This estimate is again likely to be conservative as many people are deficient in more than one nutrient.
- **Almost 30 percent of children under five in developing countries are underweight.** Underweight is a summary indicator combining acute and persistent causes of child malnutrition. The prevalence is high but has declined during the last decade, in particular in Asia and the Pacific (UNICEF). Malnutrition is directly or indirectly associated with almost half of the 9 million child deaths per year worldwide, with the highest rates in Sub-Saharan Africa.
- **According to WHO, 1.5 billion adults are overweight.** Nearly 43 million children under five were overweight in 2010 (WHO, 2011). 65 percent of the world's population live in countries where overweight and obesity kills more people than underweight (Uauy, 2011). These numbers underscore the fact that action is needed to fight undernourishment as well as overnourishment.
- Unless decisive action is taken, the number of hungry may continue to increase with rising food prices and market volatility. **Agricultural supply growth is not enough to bring hunger down** (FAO, 2009)**.** What matters is that the modalities of supply growth benefit the poor ("agriculture for development") (World Bank, 2007).

Addressing Future Problems of Food and Nutrition Security—A Double Goal

de Haen stated that there is now broad agreement among experts that to achieve the nutrition related Millennium Development Goals (MDGs) and ultimately food and nutrition security for all requires pursuing a double goal: (1) Alleviate hunger and malnutrition on a sustainable basis and (2) Create conditions for meeting the increasing demand of a growing world population.

Alleviating Hunger and Malnutrition

Addressing this first goal requires a strategy with three entry points:

(1) *Giving the poor better access to income earning opportunities.* The experience of successful countries shows that public investment in rural areas, in particular investments benefitting smallholder agriculture, generates greater reduction of poverty than does investment in non-

agriculture sectors. The majority of the poor still lives in rural areas. With further urbanization, more action against hunger will be needed in cities as well.

(2) *Social safety nets*. There is now a wide array of practical experiences with social safety nets,[4] which provide the neediest persons immediate access to vital social services, including food assistance, health and sanitation, education and training. In the absence of social protection, each reoccurrence of a crisis will force the poorest into unsustainable and often detrimental coping strategies.

(3) *Targeted nutrition improvement measures.* These may range from fortification of certain foods in some countries to training for life course approaches to address obesity risks in others.

Meeting the Growing Demand

de Haen explained that the second strategic goal requires ensuring future production growth to meet the demand of a growing and increasingly prosperous world population.[5] Whether or not the world-wide food system will succeed in meeting that growing demand on a sustainable basis will depend on the effective interplay of a number of driving factors. The most important ones are listed below.

Population growth: According to the medium variant of the 2008 UN population projection, the world population is expected to reach 9.3 billion by the year 2050. More than two thirds of that population will be urban, compared with 50 percent today. Nearly the entire increase will occur in today's developing countries, with the largest increase in Asia.

Income growth: According to the World Bank, "In most developing countries, GDP has regained levels that would have prevailed had there been no boom-bust cycle" (World Bank, 2011). With this prospect, the developing countries, especially in Asia, but also in Central and Eastern Europe and in many countries of Sub-Saharan Africa, are expected to resume their strong economic growth.

Demand growth: The projected population and income growth are likely to translate into strong growth of per caput demand for agricultural products. However, some of the more populous countries like China and Brazil are moving towards saturation levels. Thus the gradual slowdown of overall demand growth is likely to continue. According to FAO's projection to 2050, published in 2009, global demand for agricultural products is expected to grow by about 70 percent compared to 2005/2007.[6]

Resource constraints, climate change and sustainable intensification: The task ahead is daunting considering the multiple resource constraints. Until 2050, the area of agricultural crop land per person is likely to decline further; already today, 1.4 billion people are living in areas with declining ground water levels (World Bank, 2007), two thirds of the agricultural ecosystems are more or less degraded, the genetic resource base for future plant breeding is faced by various risks, and the burden of adjustment to climate change falls disproportionately on the

[4] See, for example, B. Guha-Khasnobis, S. S. Acharya, and B. Davis (Eds.) 2007. Food Insecurity, Vulnerability and Human Rights Failure. UNU-Wider.
[5] Production growth is also needed to enable today's almost one billion undernourished to increase consumption to the minimum requirements. Depending on the food gap to be filled, this would require between 30 and 50 million tons of grain equivalents, hence a small fraction of today's total supplies.
[6] Provisional estimate made in mid-2009 (Bruinsma, 2009) indicated 70 percent. This was based on projections to 2050 made in 2003-2005 (FAO, 2006). Work in FAO underway for updating the projections.

rural areas of the southern hemisphere. In view of these resource constraints, about 80 percent of the projected supply growth will have to originate from sustainable intensification (i.e., productivity growth that minimizes negative environmental implications, contributes positive environmental services and is generally integrated into an ecosystems approach) (Bruinsma, 2009).

Reducing waste and losses: In the light of the constraints to natural resources, efforts to reduce waste and losses should be seriously considered. According to various sources, waste and spoilage causing useless input of land, water, feed and energy could be in the order of 30 to 40 percent of agricultural production world-wide.[7]

Trade and market structure: Even with high growth of their own production, the developing countries as a group will face a significant widening of their net trade deficit for basic food stuffs--enhancing export opportunities for agriculture of developed countries. This perspective will make it even more important that trade rules and market structures enable poorer countries to generate export surpluses in other goods and services, including tropical products.

Perspectives for Reduction of Hunger and Malnutrition

Both main organizations with long term projections of world agriculture, FAO and IFPRI, include food security indicators in their projections. These are generated on the basis of certain assumptions regarding future changes in the intra-country inequality of access to food. While FAO's projections use the same indicator (undernourishment) that is used to monitor past food security, IFPRI uses child underweight as an indicator of malnutrition. According to FAO's latest projection (Alexandratos, 2009), using one trajectory considered most realistic, undernourishment is expected to decline. The decline is rather slow, so that the target of halving the number of undernourished between 1990/1992 and 2015, set by the World Food Summit in 1996, will be achieved only just before 2050. IFPRI's projections also indicate a decline in malnutrition. It shows in various scenarios the importance of economic development in reducing child malnutrition. In an optimistic scenario, the number of malnourished children in developing countries falls by almost 46 percent between 2010 and 2050. Child malnutrition would fall even under a pessimistic scenario, though by only 2 percent. These perspectives imply a reversal of the recent trend of rising chronic hunger. de Haen explained that none of the studies considers explicitly how alternative policies, including both production and consumption related policies, would be effective in changing that trend.

Conclusion--Main Challenges

Effective reduction of food and nutrition insecurity requires a deliberate double effort: One is action to improve the access to income earning opportunities for today's hungry and to ensure social protection, including immediate access to food for the neediest. The other is investment in sustainable, longer term agricultural growth and development. Action and behavioral change will be needed at all levels—individual, corporate, and public. Governments in all countries also have a key responsibility in establishing the enabling conditions for effective and sustainable improvements, within a framework of political stability and good governance.

[7] According to sources cited by UNEP, even "57% of the potential edible crop harvest was lost during different stages of conversion from crop to food or as food waste" (UNEP Brief, undated, "Agriculture, a Catalyst for Shifting to a Green Economy.")

They must have the political will to change priorities, mobilize public investment and reform institutions in favor of sustainable food and nutrition security. de Haen stated that a guiding principle must be combining measures to reduce hunger with investment in sustainable growth of food supplies. In many countries, this will require a focus on rural smallholders, representing the majority of the poor, but it must increasingly also address urban food security problems.

AGRICULTURAL PRODUCTIVITY AND NATURAL RESOURCE ENDOWMENTS[8]

Philip Pardey, University of Minnesota

Philip Pardey opened this session of the workshop by raising a number of critical questions—what are past and prospective rates of agricultural productivity growth, how do these rates relate to changes in demand, how have natural resource endowments changed over time, and what are the links between the flows of natural input services to and from agriculture? He suggested that there were three key indicators associated with agricultural productivity--what is produced, where it is produced, and how it is produced. Moreover, the biological processes that underpin production agriculture underscore the need for a spatially sensitive view of production, given spatial variation in the natural inputs that are distinctively used in agriculture.

Pardey stressed the importance of understanding past and likely future trends in agricultural productivity relative to corresponding changes in the demand for agricultural outputs, since differential rates of supply (productivity) and demand growth will cause agricultural commodity prices to change over time, with direct hunger and poverty consequences. He also explained that if U.S. agricultural productivity had not increased substantially between 1900 and 2008, an area equivalent to the entire area east of the Mississippi would have had to be cultivated to reach the level of cereal production attained in 2008, with far reaching natural resource consequences.

Pardey noted two sets of important drivers of productivity change that are typically ignored by traditional productivity measurements: (1) natural inputs, such as weather, terrain, and soil types, and (2) pests and diseases. All of these natural inputs vary across time and space, making it difficult to identify the degree to which these factors account for measured variation in agricultural productivity vis-à-vis the effects of other factors, including differences in the scale (and structure) of production and unmeasured changes in the quality of conventional inputs (such as land, labor and capital). He also emphasized the important productivity consequences of technological changes arising from investments in public and private agricultural research and development (R&D). However, the agricultural productivity consequences of R&D and changes in the natural resource base play out over many decades, adding to the difficulty of attributing measured changes in productivity to either of these (or other) factors. For example, almost 60 years passed from the conception of hybrid corn to its commercial release.

There are alternative, conventional measures of productivity, be they partial-, total- or multi-factor measures.[9] Consider crop yields, for example, as one seemingly straightforward and

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[8] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Philip Pardey (May 2, 2011).

[9] As Alston, Babcock and Pardey (2010, p. 452) observed, "Individual grain yield is an example of a *partial factor productivity* (PFP) measure. It is ''partial' in the sense that it only accounts for changes in the amount of land used in production. It does not account for changes in the quantities of other inputs—such as labor, capital, fertilizer,

illustrative partial-factor productivity measure. Figure 2-1 illustrates the difficulties in measuring and understanding differences among countries in average crop yields. The figure shows pixilated crop yields (on a five arc-minute grid) worldwide for four crops, with production areas stratified into yield deciles (1 being areas with the lowest 10 percent of yields worldwide, and 10 representing areas with the highest yields). The inset table indicates that in 2000 the United States accounted for 32 percent of the world's corn pixels that fall in the three highest yielding deciles, while Africa accounts for only 2.5 percent of such high-yielding pixels.

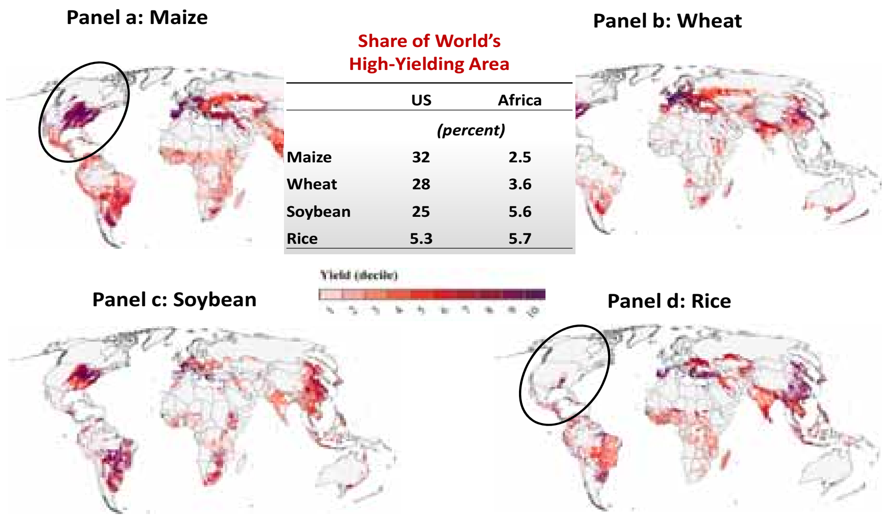

FIGURE 2-1 Spatial Distribution of Crop Yields, 2000 (SPAM ver 3.0)
SOURCE: Presentation by Philip Pardey, University of Minnesota, May 2, 2011.

Each of these pixels is associated with a set of natural resource attributes (in terms of rainfall, soil nutrients and organic matter, temperature, sunlight, and so on), and to the extent that these natural attributes affect crop yields, differences in the spatial location of production within the United States versus Sub-Saharan Africa will also affect crop yields. But these natural attributes are rarely measured, thereby confounding our interpretation of the sources of productivity (yield) differences among countries. Thus, in this instance, to what extent do differences in (unmeasured) natural inputs between the United States and Sub-Saharan Africa account for differences in average corn yields versus differences, say, in the amount, nature and effectiveness of R&D in these two areas of the world? Moreover, to the extent that the location of production within a country changes over time (and thereby the implicit mix of natural inputs), the problem of disentangling the productivity consequences of natural inputs from other factors is made doubly difficult.

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rainfall, or irrigation—that also affect production. Thus yield and other partial measures can be seen as partial with respect to their treatment of outputs as well as inputs. At the opposite end of the spectrum are measures of *total factor productivity* (TFP), the aggregate quantum of all outputs divided by the aggregate quantum of all of the inputs used to produce those outputs. TFP is a theoretical concept. All real-world measures omit at least some of the relevant outputs and some of the relevant inputs, and therefore it is more accurate to refer to the real-world measures as *multifactor productivity* (MFP) measures."

Meaningful advances in our state of understanding about the nexus between natural resources and agricultural productivity are likely to hinge on at least two fundamental factors. First is the need for a spatially explicit view of agricultural production processes given the spatial variation in the biological processes that define production agriculture. Second is the need to take a long-run perspective, likely decades rather than years, given the timeframes it typically takes for natural input cum agricultural productivity processes to play out.

ARE NEW PARADIGMS NEEDED FOR SUSTAINABLE FOOD SECURITY IN THE FACE OF UNCERTAINTIES AND RISKS?[10]

Marco Ferroni, Syngenta Foundation for Sustainable Agriculture

The world's food security is under threat because of the "double squeeze" on productive capacity, which stems from rapid demand growth and a deteriorating natural resource base, which is increasingly unpredictable due to climate change. The average annual rate of growth of cereal yields has declined from more than 3 percent in the 1980s to close to 1 percent in recent years, a level just below the rate of population growth. There is little room in this situation for the food system as a whole to absorb income growth-induced additions to demand or accommodate production shortfalls due to adverse weather. Prices had to (and did) rise, and they became more volatile as markets adjusted to such factors as changes in grain stocks relative to use, export restrictions, currency movements, fluctuations in the price of oil, financial speculation and subsidies for biofuels that added to the demand for commodities that competed with food for land and water. Globally speaking, agriculture is under stress. For this reason, many analysts and observers have remarked that, as we look to the future, "business as usual" in agriculture will not suffice.

The world needs to grow more food, in addition to taking other measures such as the reduction of post-harvest losses and waste in the supply chain. This will require new models and approaches. Going forward, the production-based approach of the Green Revolution that sought cheap and abundant supplies of food is no longer comprehensive enough. The needed increases in food production must be brought about sustainably, using natural resources wisely to be able to "indefinitely meet the requirements for food, feed and fiber at socially acceptable economic and environmental cost" (Crosson, 1992). Increases in food production can come from agricultural intensification, the expansion of the agricultural frontier, or a combination of the two. Although there are untapped reserves of land and water, to be sure (mostly in Sub-Saharan Africa, Latin America, Eastern Europe and Central Asia), most of the required growth in global production is going to have to come from intensification, because land and water are finite assets already overused in many places.

Sustainable intensification can be defined as "producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services" (Pretty, 2011). These are requirements with many implications, but the place to start is yield. Yield gaps are huge in many

[10] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Marco Ferroni (May 2, 2011).

settings as shown in Figure 2-4.[11] They need to be reduced and closed as part of intensification. Reducing yield gaps will also raise the efficiency of water use.[12] It has been shown that in grains and other field crops, the correlation between water use efficiency and yield per unit of land is high.

The literature on yield gaps is quite large, and reviewing it is beyond the scope of this presentation. One study that looked at yield gaps for major crops, and world regions recently defined five production constraints and invited a group of experts to assign weights to them to reflect their relative importance (Hengsdijk and Langeveld, 2009). The experts queried were experienced crop specialists from national and international research institutions. Figure 2-4 shows the study's estimates of the contribution of the five production constraints to the theoretical maximum yield gap for corn in different parts of the world. It is instructive to see for South Asia, for example, that the estimated yield gap is close to 8 t/ha and is thus very large, because of limited water availability, limited nutrient availability, inadequate protection of the crop from pests and diseases, insufficient or inadequate use of labor or mechanization, and knowledge deficits that result in poor crop management.

The authors acknowledge the difficulty of measuring and comparing yield potentials and actual yield across a range of conditions. Their results are indicative. But the relative contribution of the factors accounted for in Figure 2-4 is telling, and, for example, the point about knowledge as a constraint on yield makes it quite clear that there is an unmet need for agricultural extension.

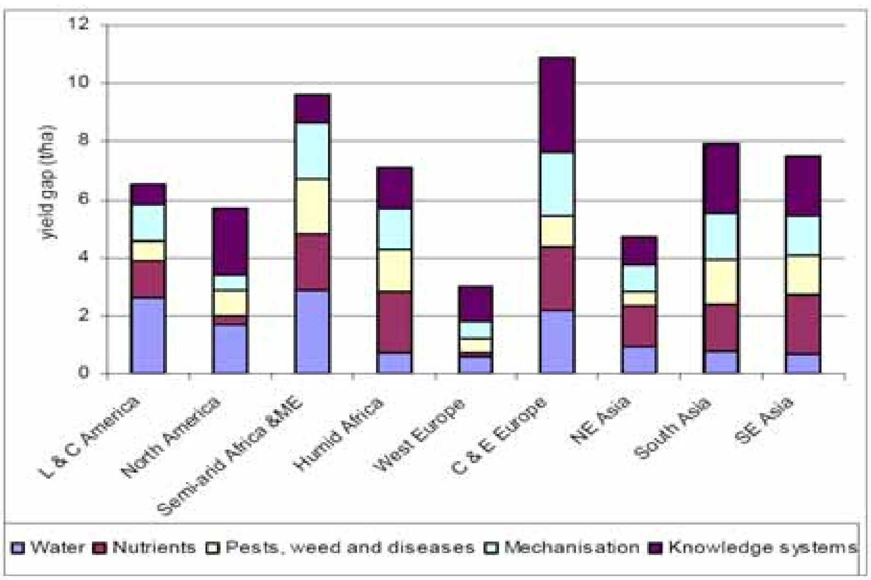

FIGURE 2-4 Maize yield gap by region and contribution of five production constraints
SOURCE: Hengsdijk and Langeveld, 2009

The task of reducing and closing yield gaps calls for appropriate farm systems management, inputs and technology, services and access to markets. Infrastructure, finance, weather data and risk insurance are among the critical components on the input side, as are functioning markets and distribution systems for seed, fertilizer, tools and appropriate

[11] Yield gap can be defined as the difference between realized productivity and the best that can be achieved with current genetic material and available technologies and management.
[12] Liters of water used to produce a unit of grain.

mechanization. Science-based advances and technology are central, including soil testing, improved seed and varieties, seed treatment, new and improved fertilizer technology, micro-irrigation, precision farming and agricultural extension. Mobile phone based applications in agriculture have begun to revolutionize the linkages and transactions between farmers and service providers of many kinds. They are the "up and coming" tool for scaling up extension and linking farmers to input and output markets.

Markets for food and agricultural commodities offer hitherto unseen opportunities for farmers, including small farmers in developing countries and emerging markets. Small farmers no longer want to be seen as subsistence farmers they are, or aspire to become, commercial producers. They are looking for ways to secure access to technology, services, infrastructure such as roads, and markets. Farmers' organizations are serving an increasingly important role in providing access to these. Although the farmers' share of the consumers' dollar at retail tends to be small, organized growers who are working the land with the right kinds of inputs and support and selling into established markets can improve their livelihoods and invest in their future.[13] There cannot be sustainability in agriculture without this. However, in many parts of the world, there remain serious barriers to expanding smallholder production: unhelpful governance and institutions, lack of public goods, inadequate services such as credit and extension services for farmers, and land fragmentation.

New paradigms are needed in global agriculture and are emerging: productivity and sustainability are inseparable, markets and consumers are driving change, and agriculture and farming remain important even as economies evolve. Approaches to the food security challenge that focus solely on production are inadequate. Intensification is called for as never before, but it must come about sustainably, heeding on-site and off-site environmental conservation and rehabilitation opportunities and needs; and adapting to, and working to mitigate, climate change. Intensification must take cues from the market and respond to the quantitative and qualitative changes in tastes and demand that are visible wherever one looks, complying with the product and safety standards that modern markets demand. Food safety, standards, and the power of consumers are part of the new reality to contend with--a reality that (together with the liberalization of markets) is shifting agriculture in developing countries and emerging markets from the grains- and staple-based subsistence focus of the past towards high-value, information-intensive, commercial farming. Many smallholders are participating in this trend successfully today; many more should be and--with the right kinds of services and support--*can* be brought into the process to help fill supply gaps, raise incomes and promote agricultural growth.

Agricultural growth and the adoption of technical progress by farmers are needed even as the sector's share in countries' GDP falls. The economic transformation whereby agricultural GDP declines rapidly relative to the total, and agricultural employment declines slowly, is in full swing. Sustainable progress and productivity growth in agriculture are needed for at least six good reasons in this context, all of which relate to and reinforce food security: food availability, conservation of natural resources, diversification of the rural economic space and rural non-farm employment, overall economic growth, poverty reduction, and income convergence between the agricultural and non-agricultural sectors of the economy. To get there, we need enlightened

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[13] Reardon and Gulati offer an analysis of how the transformation of supply chains and marketing creates opportunities and challenges when it comes to linking farmers to markets. The organization of farmers becomes essential to lower transactions costs from buyers' perspective and to raise farmers' bargaining power. See Reardon, T. and A. Gulati. 2008. *The Rise of Supermarkets and their Development Implications*. IFPRI Discussion Paper 00752.

investment in agriculture. *Farming first* is a good maxim to go by, accepting sustainability and market-driven, science and technology-based modernization as two sides of the same coin.

GENERAL DISCUSSION

Participants raised a number of questions regarding productivity increases--what this might mean in terms of prices and ways to stimulate increased productivity. One participant asked whether farmers were likely to increase production to such an extent that food prices would fall. Marco Ferroni indicated that this could happen if productivity rose enough, because farmers are price responsive. He noted, however, that abundant global food supplies and falling prices are unlikely in the foreseeable future because increases in the demand for food are expected to be very large in many developing countries as their incomes grow while production prospects are challenged by natural resource degradation and the threat of climate change.

One speaker emphasized the importance of spillover effects, noting that managing such effects is critical to promoting the use of new agricultural technologies. In fact, he suggested that part of the success of the green revolution was due to the friendship between Norman Borlaug and the Indian minister of agriculture. Other speakers emphasized the importance of continuing support for R&D and mentioned that by reducing U.S. agricultural subsidies by 10 percent and shifting these funds to R&D, U.S. public R&D funding could be doubled. It was also noted that much of the private R&D funding is not directed at food crops but rather at ornamentals—flowers, houseplants and grasses.

Ferroni stressed the importance of political commitment to agriculture, private and public investment in agricultural R&D, and technical support to farmers (for example in the form of agricultural extension) to help raise yields and productivity sustainably. He cited the example of Gujarat, a relatively natural resource poor state, where agricultural production increased up to 10 percent a year because of dedicated government support.

WATER FOR A FOOD-SECURE WORLD[14]

David Molden, IWMI

David Molden began the session by describing the link between water and food. Estimates place the need for additional food production at about 70 to 100 percent more than we produce now. More food requires more water. Agriculture now takes 70 percent of global water withdrawals. If we continue producing food the way we do now, up to twice as much would go into food production in the form of evapo-transpiration through 2050. Given that we have water scarcity now; that we have reached or surpassed limits already with groundwater decline, shrinking rivers and threatened fisheries; and that climate change brings more risk and uncertainty; we must change the way we think and act about water.

The 2007, the Comprehensive Assessment (CA) defined two types of scarcity, physical and economic (Molden, 2007). Both are related to problems of access. In regions of physical water scarcity, water is fully allocated or over-allocated to cities, agriculture and industry,

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[14] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by David Molden (May 2, 2011).

leaving little or nothing for the environment. In economically water scarce regions, water is available for use, but access is difficult because of limited investment in water infrastructure or limited human capacity to develop and manage water. In both cases, lack of access to water is a threat to future food production, but in very different ways (see Figure 2-5 below).

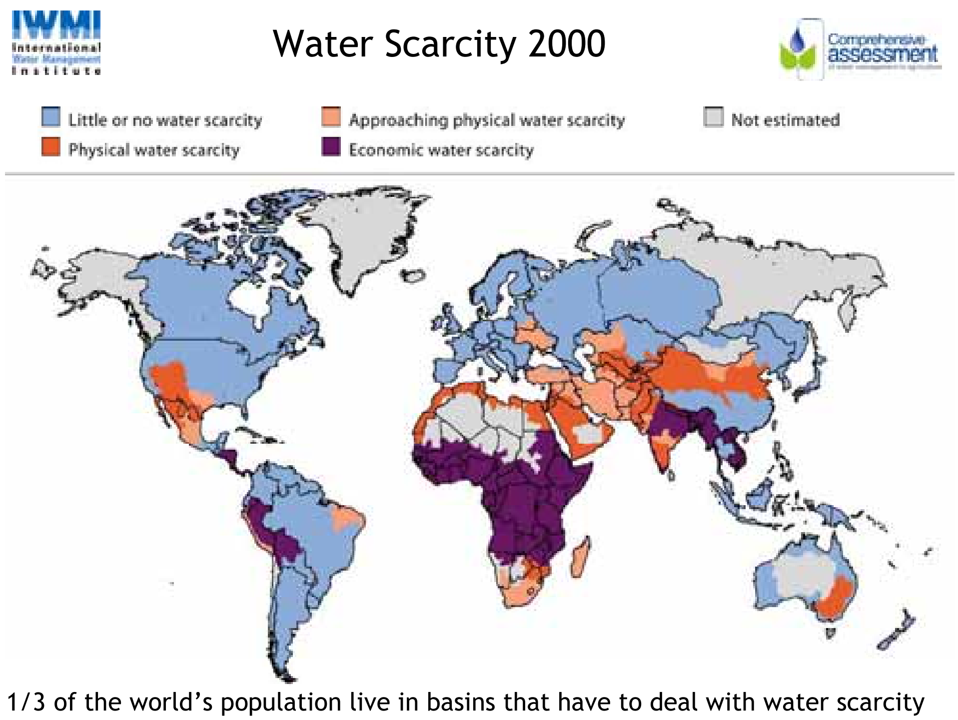

FIGURE 2-5 Water Scarcity 2000
SOURCE: Presentation by David Molden, IWMI, May 2, 2011.

Other limits have already been reached or breached in important food producing regions in ways that compound water scarcity. For example, groundwater levels are declining rapidly in several major breadbasket and rice bowl regions such as the North China Plains, the Indian Punjab, the Ogallala in Western USA (Giordano and Villholth, 2007; Shah, 2007). Rampant land degradation and nutrient depletion limits productivity gains (Bossio and Geheb, 2008). Demand for aquaculture products like fish and shrimp continues to rise (Dugan et al., 2007), which means more demand for freshwater resources to produce these products. Similarly, most of the additional animal-based food products from livestock and poultry will be grain fed, thus requiring more water, as we approach the limits to production on grazing land.

Climate change will shift patterns of water availability, increase demand from increasing temperatures, and represent a challenge to water managers with increasing variability of rainfall and stream flows.

Economic water scarcity poses a different set of problems with a different set of solutions. In these regions spread across much of Sub-Saharan Africa, South and South-East Asia, and pockets of Latin America, there is limited water access, but high scope to use more water for food production, both directly from rain and irrigation sources. A little additional water for crops at the right time can increase water productivity of water and land. This is most likely to be true in areas of high poverty, so there are poverty and productivity gains to be made

(Rockstrom et al., 2007), particularly within rainfed systems (Wani et al., 2009). Hence, it is surprising how little attention is given to water across Sub-Saharan Africa. In semi-arid areas, there is enough seasonal rain available, but short, unpredictable dry spells make farming a risky business. This variability is likely to increase with climate change. The secret to getting through dry spells is adding a little water at the right time. It has been well demonstrated that providing the basics (water, fertilizers, seeds and good farm practices) can readily lead to double or triple yields where grain yields are one ton per hectare. A reliable water supply reduces risk and encourages investment in the basic inputs.

However, the ways the water is developed and managed will be much different than the designs that served us well for the green revolution. There is a range of options that includes large-scale gravity irrigation, provision of supplemental irrigation, use of groundwater and water harvesting techniques. Increased water storage, utilizing small and large reservoirs, groundwater, wetlands, and soil moisture, is critical to providing water access and is a key climate-change adaptation measure. In fact, the division between rainfed and irrigated agriculture is academic. It would help to think of rain as the ultimate source of water and to consider agricultural water management options that include soil moisture storage, small and large irrigation, and drainage.

A set of new trends will temper water and food actions in the future. First, in some river basins such as the Mekong and the Nile Rivers, there is a marked increase in large dam construction. Related to this is the role of China in development efforts, and in particular water development efforts. Although there are efforts to increase cooperation for transboundary water management, it is not apparent that China is a major player in these discussions. There is a lot of discussion about the sudden growth in land acquisition (“land grabs”) for agriculture. In fact, these are often natural resource grabs as well, as the land is rarely so valuable without the water. Recently, the private sector is becoming increasingly interested in water, recognizing the business risks arising from water scarcity, as well as the opportunities from better water management. Finally there is a silent growth in an informal water sector, especially amongst the poor. People who do not receive water services from formal or government sources figure out how to do it themselves. Much of the groundwater use today is from that informal water economy.

There are only a few basic pathways to grow more food with the Earth’s water: continue to expand rainfed and irrigated land and water use, increase productivity of water resources, encourage trade in food commodities, and modify our food and fiber consumption practices. Large-scale land expansion for agriculture is no longer a viable solution because of ecological limitations. Although there is very limited scope for mobilizing more water in many parts of the physically water scarce world, there is scope for additional water use to intensify agriculture in economically scarce regions, especially in Sub-Saharan Africa, where irrigation is only 5 percent of its potential. Trade has potential to reduce global demand for water for food production if trade is made between areas of high water productivity to areas of low water productivity. However, water is not a key factor in influencing trade policy, and it is also difficult to imagine that poor countries could afford to purchase food to solve a global water problem. There is scope to substantially reduce future water requirements by reducing food waste and by reducing overconsumption of food. Improving water productivity will be the key where water is limited, as it will be for new water developments.

Will there be enough water to grow enough food? The answer is that it is *possible* to grow the food needed with the water we have, but it is *likely* that we will do it in ways that cause more degradation and do not address poverty if we stay on the present course. It is also possible that by judiciously applying strategies tailored to local conditions for safeguarding water access, improving productivity of water, through trade, and watching our food consumption patterns, we can limit the amount of additional water needed and can meet poverty and food security goals. These measures are necessary but not sufficient. A focus on improving water management in areas of high poverty will yield the greatest gains in water productivity, where increases in yield also translate to growing more per unit of water. This is in contrast to highly productive areas where yield gains require more water to be transpired. Managing water as an integral part of ecosystems will make our food production systems more resilient and more sustainable. Only if we change the way we think, act and govern water and food will we be able to adequately address the severe water, food, and ecosystem challenges of today and tomorrow.

LAND DEGRADATION AND SUSTAINABLE FOOD PRODUCTION: SUB-SAHARAN AFRICA[15]

Paul L.G. Vlek, University of Bonn

The state of our lands, both natural and men-appropriated, is difficult to track. That has not stopped numerous agencies from making estimates based largely on expert assessments. The most recent compilation of these assessments was made during the Millennium Ecosystem Assessment (MEA, 2005). It is estimated that around 70 percent of our land has seen degradation in some form or another, whereas 20 percent of the soils are degraded. However, the lack of a sound baseline or any ground truthing and the lack of experts, particularly in Africa, lend limited credence to these estimates.

The state of our forests areas is monitored relatively closely due to the efforts by FAO. Conversion rates are reported by national governments, and the introduction of satellite imagery has allowed verification of these statistics over the past 15-20 years (FAO, 2010). It is clear that deforestation and forest degradation will likely proceed unchecked and with losses at an annual rate of around 16 million hectares of natural forests and tree cover. In the process, livelihoods and ecosystem services that underpin agricultural productivity are lost.

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[15] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Paul Vlek (May 2, 2011).

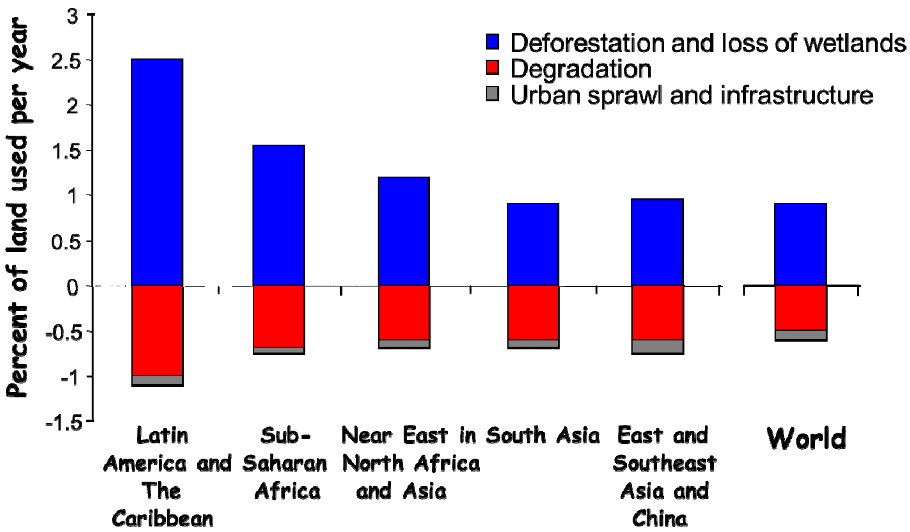

FIGURE 2-6 Change in three classes of land use 1960-2000.
SOURCE: Presentation by Paul Vlek, University of Bonn, May 2, 2011.

Deforestation severely disturbs the hydrological cycle and exposes soil to the threat of erosion. It also diminishes the carbon pool and biodiversity, thus contributing to climate change and a loss of services such as pollination. Deforestation is largely due to the pursuit of ecosystem goods through agricultural expansion and overexploitation for timber and fuel. Unsustainable logging removes the most valuable tree species and gives farmers access to complete the conversion process. The real cost of the lost ecosystem services to society is immense and is never reflected in the price of the products. In many cases, the livelihoods of the individual producers taking the land is secured through the mining of the natural resource base.

Tracking the state of our agro-ecosystems is more complex, and data are scarce. Nowadays this problem is partially overcome by the availability of space observation information in the public domain. Global coverage of satellite imagery over a two-decade time slice has spurred new efforts to quantify land degradation. The assumption in this type of analysis is that a declining biomass production can be measured as a decrease in NDVI, a blue/green-spectrum index serving as a proxy for the standing vegetation. If the NDVI monitored from space is showing a decline over the years, the underlying degradation processes on agricultural land must indeed be rather severe. In an analysis of SSA, Vlek et al. (2008) estimated that around 8 percent of the agricultural land and 15 percent of the forest/cropland area exhibited declining NDVIs between 1982 and 2003. Though this may seem modest, once added to the 10 percent that was already claimed to be severely degraded in the late eighties by the expert assessment (GLASOD), the agricultural land resources of Africa are indeed dwindling fast.

However, from a glance at the NDVI map of SSA (Vlek et al., 2008), it is immediately evident that as much land area is degrading as is increasing in NDVI, reflecting biomass accrual. This is particularly evident in regions with little or no human influence and is ascribed to atmospheric fertilization of CO_2 and NOx (Vlek et al., 2010). As this phenomenon is ubiquitous, it will have masked land degradation by compensating for degradation processes such as soil erosion or soil mining. Thus, when atmospheric fertilization is taken into account, the agricultural region in SSA impacted by human activity increases from 8 and 15 percent to nearly 30 percent for both agricultural and forest/cropland. Additionally, land degradation may be ongoing at micro-scale (patches) that it is not captured as significant in an 8 x 8 km pixel on the satellite image used. As time series of higher-resolution satellites become available, more detailed analysis on a country by country basis should better inform about the state of our land and our soils. In the absence of alternative instruments for monitoring the rate of land degradation in SSA on the ground, satellite-based systems offer the best hope for tracking the state of this vital natural resource on this vast continent. A systematic research effort should be made to verify the accuracy of the findings reported by Vlek et al. and to refine the analytical tool and interpretation of the results. Such an effort certainly would have to include ground truthing and an important assessment on agricultural productivity.

The human impact on the productive capacity of agricultural land in SSA is largely related to unsustainable soil management such as eliminating fallows, removal and burning of crop residues, produce exports and shifts to more demanding crops. The consequences are soil acidification, loss of soil organic matter and nutrients, and soil erosion. Around one million square kilometers (km^2) appear affected, 40 percent of which comprises land with inherently good soil and terrain conditions in the most productive areas of Sub-Saharan Africa, threatening food production in the long run. Approximately two-third of this unsustainable land management goes unnoticed as atmospheric fertilization (CO_2 and NO_x) is making up for some of the depleting processes, so that the actual decline in NDVI signal on agricultural land is noticeable only on 260,000 km^2 (Vlek et al., 2008).

Finally, it should be noted that land degradation in Sub-Saharan Africa is happening against a background of increasing population and deteriorating climate conditions in a food-insecure part of the world. It is also the only part of the world where fertilizer use has been stagnant over the past quarter century, stuck at below 10 kg ha^{-1} yr^{-1}. The persistent decline of biomass productivity induced by mismanagement of agricultural activities against the background of steady growth of Sub-Saharan population (about 2.3 percent annually) is increasing pressure on agricultural land, posing an increasing threat to an already tenuous food security (Vlek et al., 2010).

GLOBAL SEAFOOD—FISHERIES AND AQUACULTURE[16]

Jason Clay, World Wildlife Fund

Overview

In 2000, seafood represented 0.9 percent of caloric intake. By 2050, the portion of calories from seafood is expected to rise slightly, to 1 percent. By 2010, aquaculture accounted for more human edible seafood (e.g., excluding fish that are used to make fishmeal and fish oil) than did wild caught seafood. Going forward, any increases in global seafood production, at least for the foreseeable future, are expected to come from aquaculture. By 2010, Europe, Asia and North America led the world in total seafood consumption, measured by total weight. However, seafood is also a very important source of protein and calories for many coastal areas in

[16] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Jason Clay (May 2, 2011).

developing countries around the world. In terms of overall trade, seafood production is increasing in developing countries where fisheries have been less depleted, thanks to improved commercial fishing efforts; cheaper labor; and, in the case of aquaculture, temperatures that allow for growing year round. In the case of aquaculture, more than 90 percent of production is in developing countries, though a smaller percentage is actually consumed there.

The Status of Marine Fisheries

Most global fisheries are overexploited or fully exploited. In 1974, 9 percent of global fisheries were overexploited, and 51 percent were fully exploited. By 2006, 25 percent were overexploited, and 52 percent were fully exploited. By contrast, 40 percent of global fisheries were underexploited in 1974 compared to only 23 percent in 2006. Since the early 1990s, total catch of wild caught seafood has been stagnant or even declining slightly. And, total catch levels have been maintained as small, pelagic fish have been caught in increasing numbers to use as ingredients in animal feed, initially in pork and poultry production but increasingly in aquaculture production. Today, more than half of all fishmeal and more than 80 percent of all fish oil are used in aquaculture feed.

The most important species produced globally is the anchoveta, which is used primarily to make fishmeal and fish oil. The Alaska pollock is the most productive of the wild caught fisheries for direct human consumption.

Aquaculture

For the past 30 years, aquaculture production has increased globally at an average rate of 7-10 percent per year. Today more than 400 species are cultured. The most important aquaculture products globally by weight are carps, seaweed, and bi-valves (e.g., oysters, clams, mussels, scallops). The most valuable in terms of international trade are shrimp, salmon, tilapia and pangasius. China is the largest producer of aquaculture products, with nearly 70 percent of the global total. Asia as a whole accounts for nearly 90 percent of all production. While a few species are exceptions, the bulk of aquaculture production is consumed in the country of production.

Aquaculture production is largely a developing country industry with the exception of salmon, some bi-valve species, trout, catfish and striped bass. For the most part, regulatory requirements, zoning issues and the cost of labor push aquaculture production to developing countries.

Seafood Demand Going Forward

China is the largest player in the global seafood market, with 36 percent of the global market share. Seafood represents 1.5 million jobs and one-third of all animal protein consumed in the country. China produces as much carp as poultry. China is not just the manufacturer for the world; it is also an important food processor. It processes some 50 percent of all white fish globally. Finally, China consumes about one-third of all forage fish and fishmeal and fish oil globally.

Going forward, some animal protein analysts suggest that globally, whitefish from aquaculture (e.g., tilapia, pangasius and catfish) will equal poultry by 2050 and surpass it thereafter. It takes less than half as much feed to produce a kilo of whitefish as a kilo of poultry. The key issues that might affect global aquaculture production are the dependence on pelagic fish as feed sources (by contrast, the three species of whitefish identified above are net fishmeal and fish oil producers, meaning they produce more fishmeal when processed than they consume as a feed ingredient). Other key variables are the availability of water for freshwater species and point source pollution, given that many harvest practices currently involve draining ponds. Still, we don't, by and large, continue to hunt for red meat. Similarly, going forward, seafood is likely to come increasingly from aquaculture. And Asia will come to dominate not only seafood production but also consumption as their economies strengthen.

The sustainability of seafood is an ongoing concern. The United States has shown that it is possible to bring back many fisheries once they are depleted. It is likely that other countries will attempt to follow the same path. It is difficult to bring back large fisheries that extend across multiple countries. To date, we do not have good examples of major fisheries that have bounced back—at least quickly—from overfishing. Similarly, aquaculture has had significant impacts in the past. To put it in context, aquaculture has been on a very steep learning curve. Agriculture and livestock production have had thousands of years to improve. Global aquaculture, by contrast, has had only a few decades. However, aquaculture has made tremendous strides in reducing the key impacts to more acceptable levels even as production has increased significantly. Waste in aquaculture means not just pollution, but also lost profits, so there are real incentives to improve performance. By contrast, many wild caught fisheries are subsidized and by contrast have fewer direct incentives to improve.

PRODUCING MORE FOOD AND MORE BIODIVERSITY: IS THERE POTENTIAL FOR BOTH?[17]

TG Benton, Leeds University

The Food Security Challenge

Global demand for food will grow at a greater rate than the population, and although there are uncertainties, the most widely cited prediction is the FAO estimate that 70 percent more food will be required by 2050 (Bruinsma, 2009). Despite the potential for decreasing post-harvest losses, it is likely that global food production will need to continue increasing at rates similar to those of the last two decades (UK Foresight Programme, 2011). There is some space to expand the global land area under agriculture (Fischer et al., 2002), but this is necessarily limited. First, some of the potential land is forest, and as deforestation is the second major driver of GHG (Smith et al., 2010), using this land in agriculture is counterproductive, as it would increase the rate of climate change. Secondly, productive land is typically the first to be used for agriculture, suggesting diminishing returns if cultivation expands into marginal areas. Thirdly, non-cropped land supplies many other services (from habitation to tourism to carbon storage) (TEEB, 2010), creating strong competition limiting the growth of the global agricultural landbank.

[17] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by TG Benton (May 2, 2011).

At the same time, as global demand is increasing, there is also growing recognition that agriculture needs to become more environmentally "sustainable" (in the sense that degrading services should not impact on future generations (WCED, 1987)). The value of the ecological services provided in agricultural landscapes is only just beginning to be recognized (Costanza et al., 1997; TEEB, 2010), but there are clear indications that ecology has a direct value in production systems (as well as its cultural values) and may become more important in future agriculture, especially when chemical inputs and mechanization may be restricted by carbon costs.

Benton noted biodiversity conservation can be seen as a positive that will ultimately increase yields rather than the typical "either/or" choice. Natural systems provide a broad range of ecological services, including provisioning services (such as biodiversity producing a range of provisions to fulfill the needs for nutritional security, fiber and fuel), supporting services (such as pollination, natural enemy services, soil fertility, carbon storage, soil protection, flood protection, etc.) and cultural services (creating the market for ecotourism, etc.). The value of the ecological services is gaining recognition (Costanza et al., 1997; TEEB, 2010), with some services assisting a farmer's yield and others providing more disbursed services of value to society in general. For example, 15-20 percent of total crop production arises from plant species that are wholly or partially animal pollinated (Klein et al., 2007), amounting to a direct contribution of about 10 percent of all food production at an annual value of $153 billion (Gallai et al., 2009). Similarly, "natural enemy" services provided by a range of insects and arachnids, such as small wasps, beetles and spiders, suppress pest outbreaks.

To explore the tension between production and conservation, it is useful to think of agricultural *landscapes* as systems that produce two sorts of products: food (and other economic goods like fuel, fiber, etc.) and ecosystem services (which may relate to biodiversity, water, carbon storage or environmental health). In a very simplistic sense, there are two basic land management strategies: land can be (1) farmed extensively over the farmable area, thereby producing less food but more ecosystem services on the same land ("land sharing"), or (2) farmed intensively over a smaller area, and the remaining land can be "saved" to be managed exclusively for ecosystem services ("land sparing") (Green et al., 2005).

Reaching for Solutions

Value Ecosystem Services (ES) and internalize this value to land managers

The services provided by biodiversity are often underappreciated. Furthermore, provision of services is seen as a common good provided by nature, and therefore external to the system. In production landscapes, recognizing the value of pollination and natural enemy services should help land managers value the management of non-crop areas that act as a reservoir. In the developing world, a variety of community-based approaches are happening to ensure that appropriate action is taken at the community level to preserve the services that aid livelihoods.

Value ES and internalize this value into global markets

Internalizing the values into production costs is also key for many services that have little direct value to landholders. For example, carbon storage (in soils or in non-cropped forests) may be a negative value for landholders, although positive to society at large.

Recognize the range of local-to-distant impacts and value them appropriately

Local actions can have distant impacts, and only through valuing both the near and far impacts will people be able to make informed choices. Again, this requires more sophisticated knowledge and valuation than hitherto. For example, how does environmental protection within the EU trade-off against an increased need to import produce from the developing world?

Incentivize landscape design

Governance is a key to conservation and agro-ecology because ecology is in some sense external to humanity's typical reasons for owning and governing land. In production landscapes, land managers are often seen as independent actors (both independent of each other and of the landscape context in which they act). There are many "easy gains" to be made from designing appropriate networks of non-cropped land and incentivizing local land managers to work towards realizing them.

Incentivize appropriate consumption patterns

In the developed world (and increasingly in parts of the developing world), the abundance of food at a low relative cost creates an "all you can eat" culture. Reducing demand through encouraging lifestyle change will create many positive effects, from health to environment. Changing food culture is a key route towards reducing the pressure on agricultural systems and therefore enhancing conservation (Clay, 2011; Godfray et al., 2010).

Incentivize "sustainable intensification"

It is clear that per-area agricultural productivity needs to be maintained where it is already close to optimal, or increased in the large proportion of the world where it is suboptimal. The challenge is to grow productivity globally whilst protecting the value of the environment. The solution requires (1) thinking at multiple scales, enabling smallholder farmers to raise production whilst minimizing impacts via agro-ecological farming; (2) finding ways of maximizing productivity whilst reducing environmental impacts in production landscapes; and (3) devising ways to value local vs. distant impacts.

SOIL QUALITY OF TROPICAL AFRICA: AN ESSENTIAL ELEMENT OF IMPROVED AGRICULTURAL PRODUCTIVITY[18]

Uzo Mokwunye, Development Strategy Consultant

The majority of the 800 million people who inhabit Sub-Saharan Africa (SSA) live in rural areas and depend on agriculture for employment and livelihood. But the past three decades have witnessed a stagnant or declining growth in agriculture. Thus, as at 2009, the Food and Agriculture Organization of the United Nations (FAO) recorded that more than 265 million people in Sub-Saharan Africa were hungry and malnourished and that the region remains the only part of the world where the absolute number of the poor and people facing hunger and malnutrition is increasing. To begin to understand why the agriculture sector has underperformed, it is vital to understand the nature of the soil quality of tropical Africa.

[18] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Uzo Mokwunye (May 2, 2011).

Soils of tropical Africa were formed from rocks of Pre-Cambrian origin. These rocks are made up of granites, quartz and quartzite-like materials. Soils formed from these materials are typically sandy. They are dominated by low activity clays that have very limited capacity to hold on to the exchangeable bases such as calcium and magnesium that are required as food by plants. We can therefore say that these soils have inherent low fertility. This situation has not been helped by the high temperatures and heavy rainfalls that are characteristic of the region. The high temperatures and heavy rainfall promote weathering of the rocks and the leaching of the nutrients released during the weathering process to zones where they cannot be utilized by growing plants. Although the high temperatures and heavy rainfalls encourage the growth of vegetation, these same forces promote the rapid decay of dead organic materials. The result is that the soils have very low amounts of organic matter. Soil organic matter is crucial, as it is the main source of nitrogen, a key nutrient for plants. Soil organic matter is also important for maintaining the buffering capacity of the soil. A soil with high buffering capacity reacts more slowly to changes brought about by management practices such as the addition of inorganic fertilizers.

Having been dealt a difficult hand by Mother Nature, how was the tropical African farmer able to grow food for the family? The farmer was keenly aware of the fragile nature of the soils that she/he worked and adopted a system described as “shifting cultivation” for the management. This practice enabled the farmer to cultivate a piece of land for one or two years. The piece of land was then left to fallow for upwards of fifteen to twenty years to regenerate its fertility. This practice worked as long as the population was small. With increased and increasing population, farmers have been forced to stay on the same piece of land. This intensive cultivation has resulted in massive losses of plant nutrients, a process now described as “nutrient mining.” It has been determined that by 2002, 132 million tons of nitrogen, 15 million tons of phosphorus and 90 million tons of potassium had been lost from 37 tropical African soils in 30 years.

The most efficient way to improve the soil fertility is through the use of fertilizers, primarily inorganic fertilizers. However, data from the International Fertilizer Industry Association (IFA) shows that tropical Africa is not a significant producer of inorganic fertilizers. Therefore, if agricultural production must be boosted through the use of inorganic fertilizers, such products must be imported. However, because many countries in tropical Africa have no access to ports and because of poor transportation infrastructure, fertilizer prices are very high. For example, 1 metric tonne of urea costing USD 90 in Europe would cost USD 400 in Mombasa or Beira on the East African coast, USD 500 in Western Kenya and USD 700 in Lilongwe (Malawi). At these prices, most smallholder farmers cannot afford to buy the fertilizers needed to improve the fertility of the soils (see Figure 2-7).

FIGURE 2-7
SOURCE: Presentation by Uzo Mokwunye, May 2, 2011

At the beginning of the new Century, African Heads of States and Governments adopted the Comprehensive Africa Agricultural Development Programme (CAADP)[19] as the framework for the development of the overall economy of Africa. The African leaders committed themselves to allocate a minimum of 10 percent of national budget to development in four priority areas known as Pillars. Pillar 2 expressly addressees the improvement of rural infrastructure and trade-related capacities for access to markets. In 2006, the heads of state and governments met at Abuja at the Africa Fertilizer Summit and declared fertilizer as a "strategic commodity without borders." Africa's political leadership is thus well aware of the importance of providing adequate support to agriculture. Africa's friends and development partners must hasten to the aid of the governments as they struggle to implement CAADP.

GENERAL DISCUSSION

Several participants raised questions about the link between conservation of biodiversity and agriculture. Laurian Unnevehr began the discussion by talking about a potential conflict in the Salinas Valley with pressure to clear away grasses and other vegetation from fields and water conveyances as a way of assuring the safety of livestock products. Tim Benton suggested that the need to make such tradeoffs is relatively common. He noted that if the ecosystem services being provided by these resources is limited, then the benefits of increased food safety could easily outweigh the biodiversity benefits. The need to value ecosystem services and balance these services against other factors was prominent in the discussion with Benton, emphasizing the need to educate farmers, especially in developing countries, about the values obtained from biodiversity such as pollination, flood protection, and soil fertility, as well as fuel and fiber.

Other participants raised questions about organic farming and whether or not organic farming was likely to be a major contributor to meeting world food needs. Most participants suggested that organic farming was a useful model of good farming practices that could be more widely adopted but that its contribution to providing needed increases in food crops was very limited. One participant in fact noted that if the United States and the EU moved to exclusively

[19] This program is carried out under the New Partnership for Africa's Development (NEPAD). See http://www.nepad-caadp.net (accessed on October 6, 2011).

organic system farming, more than twice the amount of land currently under cultivation would be required, with its attendant environmental costs.

A number of participants talked about the role and importance of international trade in agricultural commodities as a way to meet the needs of food-deficit countries. Though many stated that this was important, others emphasized that poor people can not afford imported food and also that in many countries expanding agricultural production is a key ingredient for long term economic growth.

FOOD SECURITY, FARMING AND CLIMATE CHANGE TO 2050 SCENARIOS: RESULTS AND POLICY OPTIONS[20]

Gerald C. (Jerry) Nelson, IFPRI

Jerry Nelson set the stage for his presentation on climate change and food security by reminding participants that today's food security challenges are unprecedented. World population is expected to increase by 50 percent between 2000 and 2050, with almost all of the increase in developing countries. At the same time, income growth in developing countries will increase demand for high value foods such as meat, fish, fruits, and vegetables. And climate change will be a "threat multiplier," affecting cropping systems worldwide.

Nelson's presentation focused on three major themes: the current state of knowledge about climate change; the impact of climate change on crop yields, supply, demand and trade; and the assessment of the challenge of long term food security with and without climate change.

Basing his discussion on direct climate change effects on a suite of four possible climate futures, Nelson stated that average temperatures would likely increase substantially--especially after 2050--and that major changes in precipitation patterns are possible. He also said that there will be increased variability in temperature and precipitation patterns. He pointed out that there are big differences among model outcomes in terms of the location and magnitude of these changes. Nelson noted that the combined effects of higher temperatures and more varied precipitation were likely to have widespread negative consequences for agricultural yields. Average increases in temperature alone would have some impact on productivity, but if temperatures spike during critical growth periods, crop yields would be much more seriously affected than average temperature increases would suggest.

Important outputs of the scenarios are estimates of future changes in precipitation. Interestingly, the two models, one from the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) and the other from the University of Tokyo's Center for Climate System Research (MIROC), yield very different outcomes. The CSIRO model has smaller and more evenly distributed increases in precipitation, whereas the MIROC model has larger average increases with decreased rainfall predicted in important world agricultural regions. See slides below (Figure 2-8; 2-9):

[20] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Jerry Nelson (May 2, 2011).

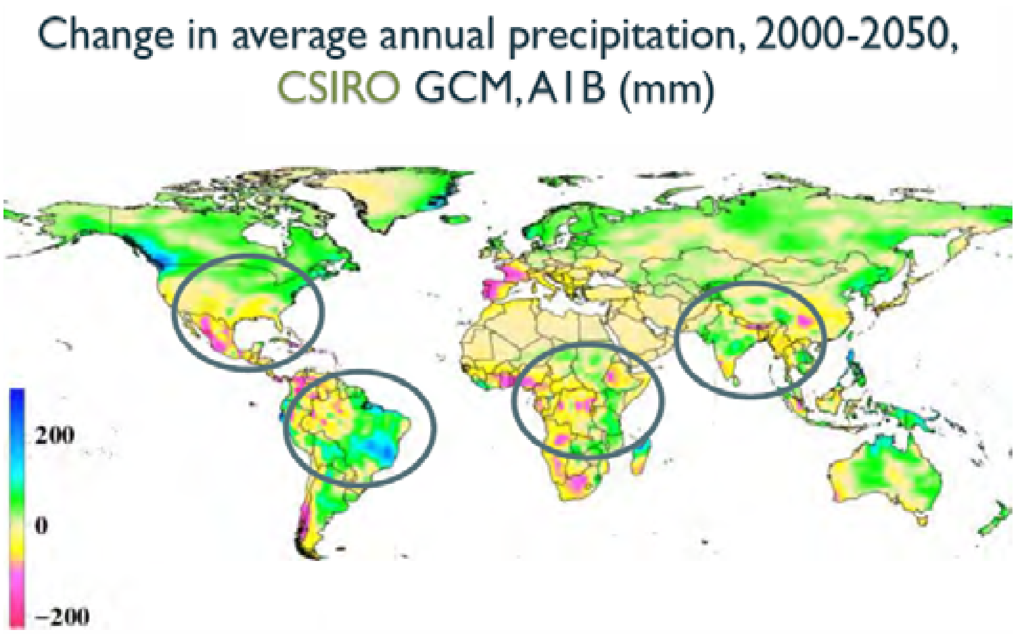

FIGURE 2-8 Change in average annual precipitation, 2000-2050 CSIRO GCM, AIB (mm)
SOURCE: Presentation by Jerry Nelson, IFPRI, May 2, 2011.

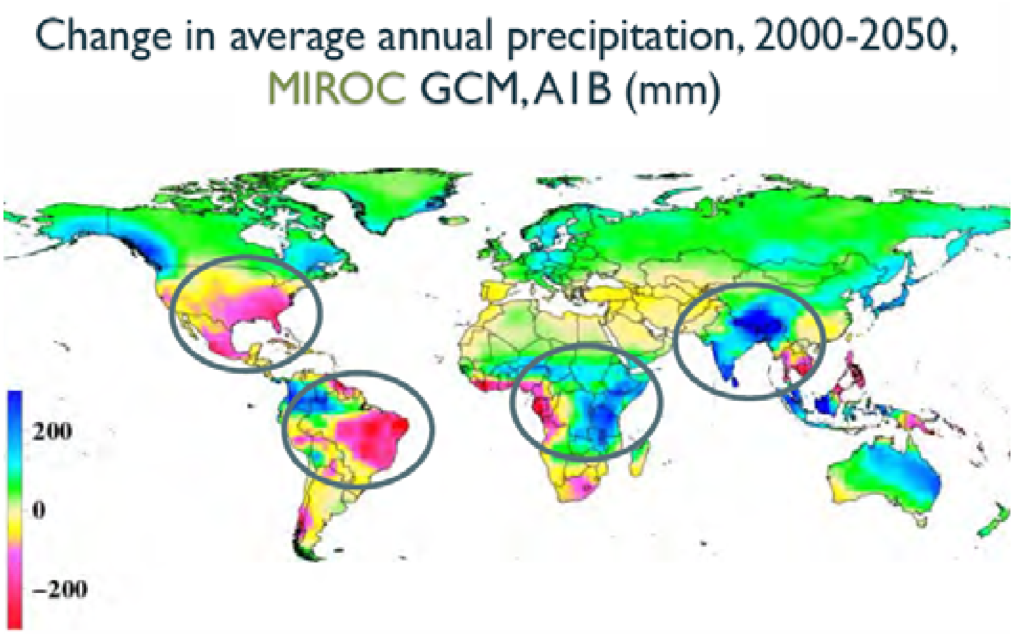

FIGURE 2-9 Change in average annual precipitation, 2000-2050 MIROC GCM, AIB (mm)
SOURCE: Presentation by Jerry Nelson, IFPRI, May 2, 2011.

See the slide below (Figure 2-10), which displays changes in maize yields with the MIROC model outputs.

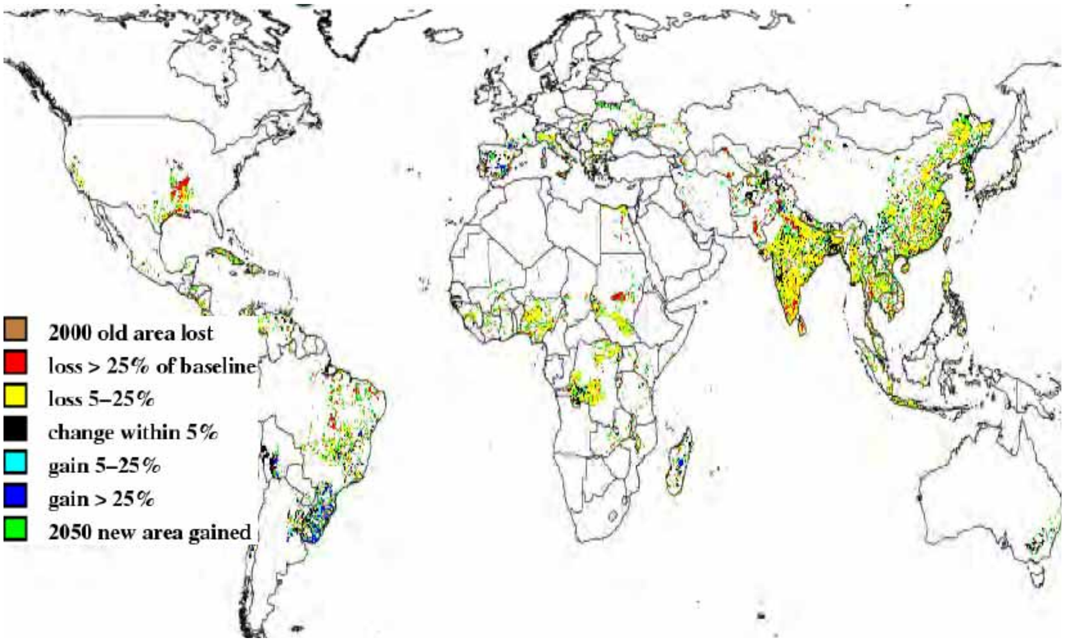

FIGURE 2-10 Yield Effects, Irrigated Rice, MIROC AIB (% change between 2000 and 2050 climate)
SOURCE: Presentation by Jerry Nelson, IFPRI, May 2, 2011.

Nelson described a set of plausible scenarios developed by IFPRI based on three overall income/population scenarios and five climate scenarios for a total of 15 plausible futures. World prices are an important indicator of the combined effects of income, population and climate. The slide below shows both the mean price increases with and without climate change as well as the range of increases that arise with different climate scenarios, holding income and population growth patterns constant.

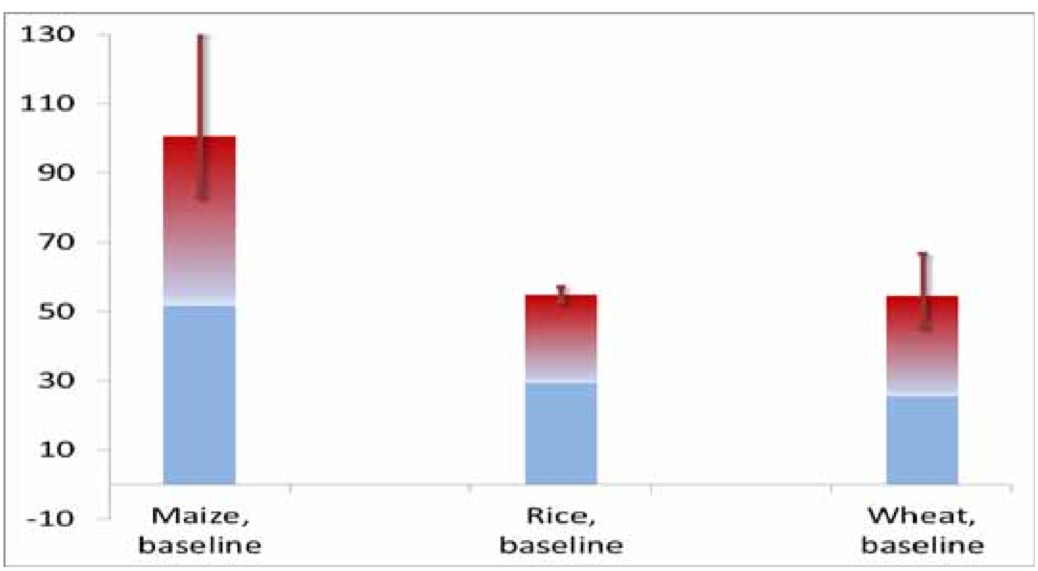

FIGURE 2-11 Climate Change Scenario Effects Differ (The vertical axis represents price increase [%], 2010-2050, Baseline economy and demography)
SOURCE: Presentation by Jerry Nelson, IFPRI, May 2, 2011.

In order to increase food security and resilience to climate change, Nelson suggested that three specific objectives must be met: broad based economic growth, investments targeted to increase agricultural productivity, and strengthened international trade agreements. He emphasized the need to raise poor people's incomes to achieve food security and increase climate change resilience. The scenarios described above suggest that the benefits of broad-based economic growth are greatest in middle income countries where there could be as much as a 50 percent decline in the number of malnourished children under an optimistic scenario. A pessimistic scenario results in a decline in the number of malnourished children of only about 10 percent on average, with a 20 percent *increase* in low-income developing countries.

Nelson said that although it is still possible to expand the amount of land under cultivation, most productivity increases are likely to result from increasing investment in existing agricultural lands. Such investments should focus on expanding irrigation and improved irrigation efficiency, biological research, and the expansion of rural roads.

He concluded that future climate variability will likely stimulate expanded trade flows from countries experiencing expanded agricultural production levels to those with contracting levels of production. Trade should help reduce some of the human suffering likely to occur from food shortages.

RISKS AND VULNERABILITIES FROM CLIMATE CHANGE[21]

David Lobell, Stanford University

This presentation focused on the risks that climate change poses to global food production. David Lobell noted that the emphasis on global scale should not detract from the fact that different regions could be affected differently, or that different uncertainties may be more relevant at some scales than at others. Below is a brief summary of the main points of the presentation.

Climate change represents a significant challenge to maintaining productivity growth rates in global agriculture.

Early work on this topic suggested that the benefits of higher CO_2 should more than compensate for any climate-related losses in global productivity until 2-3°C of global mean temperature increase. These assessments predicted that climate change would hurt developing countries before that time, but that gains in higher latitudes would buffer the global impacts. More recent work has painted a slightly more challenging picture, for two main reasons. First is that the harmful effects of warming appear stronger than initially thought, in particular for the effects of extreme heat on crop production. Early model results often suggested that adopting longer maturing varieties or earlier plantings would be an effective adaptation, but the fact that extreme heat is damaging and not included in most models challenges this view. In particular, there is little evidence for greater tolerance of extreme heat for corn grown in hot vs. cool locations.

[21] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by David Lobell (May 2011).

Second is that the beneficial effects of CO_2 as measured in chamber or greenhouse experiments seem to be higher than what has been observed in field experiments. This appears to reflect the fact that moisture conditions in enclosed experiments were generally lower, which led to strong effects on water use efficiency, which were misinterpreted as photosynthesis effects. Although some modelers have claimed that the values used in past model assessments agree with field experiment results, it appears that the modeled responses that include water use efficiency effects are indeed much stronger than observed.

In addition to CO_2 and temperature, changes in drought frequency are likely throughout much of the tropics and subtropics, and increases in pest and disease pressures will likely be more severe in several regions. Moreover, floods are increasingly common and will likely continue to be so, and ozone damage (which is in part facilitated by higher temperatures) is substantial. The effects of all of these changes are still poorly quantified at the global scale, but in sum they are likely to represent a significant challenge to maintaining productivity growth.

Adapting to climate change is likely to be one of the handful of key factors going forward (along with increasing input use and efficiency, maintaining rust and disease resistance…).

Given the above considerations, our ability to adapt to climate change is one of the major uncertainties in future food supply. It is equally or more important to increase input use in Africa, to increase the efficiency of input use globally, and to improve resistance to major rusts and diseases. All of these, including climate adaptation, are of course linked to an underlying challenge---the declining investments in agriculture and the long time lags in the system (as emphasized by Pardey's talk[22]).

The clearest risk (estimation) is from extreme heat, the main opportunity is higher CO_2.

Despite much attention and concern about changes in precipitation, and the significant role that rainfall changes might play at regional scales, the global challenges result mainly from increased temperatures. Note that this does not diminish the importance of drought tolerance, because trends in drought are often driven by greater evaporation rates associated with warming. Targeting crop development to higher CO_2 environments represents an untapped strategy that could more fully exploit the benefits of higher CO_2.

The clearest problem crops are wheat and maize (assuming that rice continues to have water, and that roots/tubers benefit a lot from CO_2).

Although maize is typically thought of as a heat tolerant crop, it is already grown in some of the harshest environments where further warming will be detrimental. Wheat is a cool season crop, which is hurt in most places from warming. A possible exception is where warming allows one to switch from spring to winter wheat varieties. Rice appears less sensitive, although it is still affected. In particular, rice is damaged from high day temperatures during flowering, which can cause spikelet sterility. Tuber crops appear in experiments to benefit the most from higher CO_2, although their sensitivity to temperature and moisture changes are less well known.

[22] See Agricultural Productivity and Natural Resource Endowments, Philip Pardey, in Chapter 2.

The public sector can play an important role in adapting, particularly in regard to genetic conservation, heat stress and CO_2 responsiveness.

The private sector will obviously play an important role in innovation, in particular for developed countries and for crop traits that are already considered important for yields (such as drought, which is increasingly the target of seed companies). But for crops without a large private sector, and for traits without much interest in current climate, there is a need for sustained public investment. This is especially true given the lags in return on research investments, which means that crops being developed today will likely reach farmers in a significantly warmer world, and one with higher CO_2.

There are very likely already sizable losses being incurred from climate change, which at a time of biofuel mandates and high prices, translates to ~$50 billion per year.

The results of a recent analysis were presented, which examined effects of changes to date. Although climate change is often thought of as a risk to future production, many regions have already experienced significant shifts. The analysis revealed a few important points: (i) The warming rates are such that net negative impacts at the global scale are apparent. (ii) Even with positive effects of higher CO_2, the sum of climate and CO_2 trends has been negative. This is not exactly analogous to the studies mentioned in the first point above, because we examined actual climate trends, not the component of climate trends forced by higher greenhouse gas concentrations. (iii) There are important differences between crops, with maize and wheat showing losses (see the fourth point above), but rice and soybean less so; (iv) There are important regional differences, with North America less affected than other regions. Whether or not these same regional differences persist will depend on better understanding the causes of recent regional climate trends. Overall, the impact of warming could be affecting productivity enough to alter conclusions from analysis of trends in multi-factor productivity discussed by Pardey and others, and also represents a likely minor but non-trivial cause of the increase in food prices over the past decade. The results suggest that the added stress from warming since 1980 leads to roughly $200 billion in lost productivity, representing a big payoff for effective adaptation. Gains from higher CO_2 likely offset about three-fourths of this loss. Although $50 billion per year can be viewed as a small fraction of overall agricultural value, the impacts are likely to grow with time, as illustrated in the previous talk. Lobell stated that the fact that we already see sizable effects means that adaptation efforts are useful not only for the future, but also for today.

GENERAL DISCUSSION

The discussion following the climate change presentations focused largely on the models used in the analysis—the elements included in the models and the extent to which potential impacts were not assessed. One speaker noted that an important effect of climate change is dramatic changes in the length and timing of the growing season. He noted that these changes may require farmers to shift from traditional crops to other crops that are easily adapted to changes in the growing season as well as changes in the length of the rainy season. Other speakers noted that the IFPRI model assumes that the supply of land is very inelastic--that large price changes in crop prices will not cause much change in net agricultural land. Other models discussed by Gerry Nelson assume the land supply is more elastic, and this is a major reason for differences in results from various models of long run changes in global agricultural output growth.

Several questions were raised about the potential impacts on agriculture of increased CO_2 levels. David Lobell said that these increases could decrease the amount of water consumed in forested areas, making more runoff available for agricultural crops. But he noted that higher projected temperatures and evaporation rates could reduce this effect. In addition, he noted that increased CO_2 helps most when crops have sufficient nitrogen. But in many cases, African soils have limited nitrogen, and the costs of nitrogen based fertilizers are high, so the increased CO_2 is not likely to spur productivity increases in Africa. Another issue not generally included in the climate models is the potential increase in ozone levels, which tend to decrease agricultural yields.

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3

APPROACHES TO ACHIEVING SUSTAINABLE FOOD SECURITY

The second segment of the workshop focused on the approaches to achieving sustainable food availability at affordable prices: the road to sustainable food security for all for the foreseeable future. Several potential approaches to achieving sustainable food availability were discussed. The session began with discussions on farm-level sustainable intensification, food value chains for smallholders leading to sustainable intensification, and sustainable ecosystem management while expanding food production. Subsequent speakers talked about barriers to sustainably increasing the productivity of crop yields and the need for increased energy efficiency in production systems. There were also sessions examining private investment and farm size issues, the losses and wastes in supply chain, global governance of natural resources, and international consensus on food safety issues. Most of these already have champions, and many have undergone some pilot testing, providing some information on strengths and weaknesses. Presenters took this learning and experience into account and provided subjective assessments as to scalability and broad impact, impact on affordability of food, and relative contributions to sustainability. Each session was followed by a brief question and answer period.

FARM-LEVEL SUSTAINABLE INTENSIFICATION[23]

Mike Bushell, Syngenta Global R&D

Mike Bushell discussed farm-level sustainable intensification from the private sector perspective, reiterating the challenge to find sustainable ways to feed a population now forecast to grow beyond 10 billion (United Nations, 2011). Substantial efforts have gone into considering this grand challenge since the 2008 food price crisis (UK Foresight Report, 2011). It is recognized that production of food must substantially increase but that environmental impacts from intensive agriculture must be reduced as well. Extensification of agriculture, bringing more land into production under lower yielding systems, is widely seen as an unacceptable solution given the limited land bank available, the large greenhouse gas (GHG) emissions that result from land use conversion, and the associated catastrophic impacts on biodiversity, particularly from deforestation.

Sustainable intensification of agriculture requires that both agricultural productivity and environmental outcomes are preeminent (Pretty, 2011). It is clear that this challenge, to "grow more from less" (Syngenta) must be met by increasing productivity of land use. One opportunity is the "yield gap," where high performing farmers can achieve yields several times greater than their neighbors; yields for rice in Asia and wheat in Europe can vary between less than 1 t/ha and greater than 10 t/ha. By understanding the limitations on yield, which are often related to lack

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[23] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Mike Bushell (May 3, 2011).

of agronomic skills, knowledge and technology access, productivity of all the major crops can be substantially increased even using basic technology available today.

Advances in developing world agriculture require *inter alia* investments in infrastructure, development of local markets, financial instruments such as availability of credit and insurance, effective national social policies on land rights and gender issues. Public private partnerships will be an important part of developing local solutions.

Modern technologies will be important but will not be the only limiting factor. Technologies are available today to accelerate the development of new seeds with higher genetic potential based on advances in genetic knowledge, phenotyping and marker assisted breeding. Genetically modified (GM) crops, which have been a central part of the yield gains in United States and Latin American agriculture, offer significant yield growth potential in many areas, such as India and China. Their true potential may be limited in Europe and Africa if effective and proportionate regulatory frameworks remain elusive.

Modern approaches to the development of new agrochemicals that set even higher standards of efficacy and safety in use are underpinned by sophisticated technologies for design, synthesis and analysis, and also by advances in formulation science and application technology. There is still huge demand for innovation in developing products with new modes of action, particularly to counter the threat of resistance development.

Integrated solutions are attractive, since creating genetic potential in a seed is only part of the story. *Yield potential* depends on seed genetics and favorable soil fertility through effective fertilization and water availability. Without effective crop protection, 40-50 percent of the food today simply would not exist; it would be lost to weed competition, insect and disease damage (Oerke, 2006). All technologies must be used responsibly, and the regulatory requirements for modern crop protection chemicals are the most stringent of any technology area. The largest component of the $250 million research and development (R&D) investment needed to bring a new active ingredient to market, is the mammalian and environmental safety profiling, which ensures that products can be manufactured and used safely.

Water is a particular concern and may be the limiting factor in agricultural productivity in many regions where groundwater reserves are being used unsustainably (see Figure 3-1). There will not be any magic solutions, but better systems for water use efficiency (WUE) can certainly be developed. Almost all aspects of the farm system can affect WUE. A lot of irrigation water is wasted (as much as 40 percent in some cases) through inefficient application. Crop enhancement chemicals (Bushell, 2009) can increase “crop per drop” by enhancing yield and reducing irrigation requirements. Seed treatment chemicals, such as Cruiser™, activate biochemical cascades within plants protecting against stress, creating vigorous, more extensive root systems that contribute to higher yields under water- or nutrient-stress situations. Crop genetics improvements also are an important area of research. The first drought tolerant corn varieties have been launched in the United States in 2011. In high value crops such as fruit, nuts and vines, drip irrigation holds a lot of promise for reducing total water usage and increasing WUE, as well as enabling better nutrient use efficiency through fertigation. Drip irrigation can also be effective in crops like rice, but may be too expensive an investment for widespread use in field crops. The tools do not have to be complex. For example, the PaniPipe project in Bangladesh involves locating short plastic pipes in paddy fields that allow farmers to easily see the water level and optimize their use of irrigation water—avoiding overuse in situations where perfect leveling is not possible. This led to a 46 percent reduction in water used and a large profit increase for the farmers.

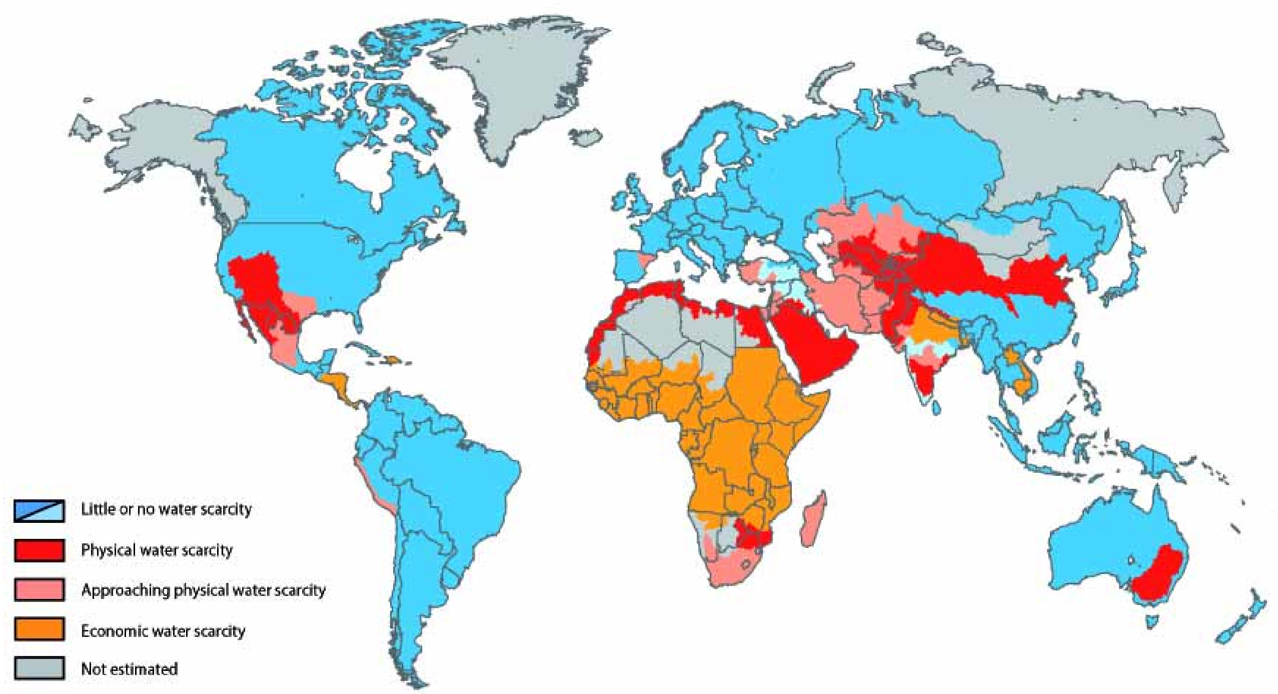

FIGURE 3-1 Areas of physical and economic water scarcity.
SOURCE: Bushell 2011; IMWI Report, Insights from the Comprehensive Assessment of Water Management in Agriculture, 2006, p. 8.

The biggest negative externality of intensive farming is arguably the diffuse contamination of water bodies with run-off from agricultural fields. Intense rainfall events can physically wash soil particles off fields, carrying fertilizer and pesticide residues into ditches and streams. The downstream effects of nitrogen (N) and phosphorus (P) pollution can result in creation of algal blooms, eutrophication and even "dead zones." Landscape planning can help minimize these effects, using high-resolution GIS to identify high risk areas at a regional, watershed and farm level. Areas of particular risk are those where the principal risk factors are found together (i.e., areas where crops are planted on shallow soils on an impervious base, with a slope greater than 2°. Fields can be identified where run-off risk is highest and effective mitigation measures can be discussed with the farmer (could be enhanced watercourse protection through buffer strips or woodland, use of no-till or cover crop practices, or in some cases not using particular products or growing crops at all). A 10 meter margin can reduce run off by 90 percent (Reichenberger et al., 2007), but in practice these benefits may not always be fully delivered. By understanding the specific farm environment and the elements that favor the flow of water (paths, ditches, slope) and elements that limit or channel the flow (hedges, woodland, grass strips, wet meadows and reed beds) better environmental outcomes can be delivered through smarter design of buffer zones.

Integrated approaches involving responsible use of technology and better planning at a systems level on the farm show a lot of promise; indeed they will enable more of the benefits of intensification to be delivered with less of the negative externalities. This can happen on any scale, from megafarms in Brazil to smallholders in Asia or Africa. More sophisticated, sustainable intensification of agriculture approaches will be enabled by improvements in extension services and use of modern information systems for knowledge transfer to farmers. Yet the principal limitations for smallholders may still be in poor infrastructure or in inability to link to input or output markets, and these require a national government approach, where again spatial planning for land use could be beneficial in synchronizing investments and avoiding conflicts over land use or competition for natural resources. Access to credit or instruments like crop input insurance will also be important to help increase financial resilience in the face of the risks and uncertainties of farming in the future.

FOOD VALUE CHAINS LEADING TO SUSTAINABLE INTENSIFICATION[24]

Maximo Torero, IFPRI

Maximo Torero discussed food value chains for smallholders leading to sustainable intensification, introducing the topic by describing the evolution of agriculture over time. There has been a decline in the agricultural importance of grains and other staple foods, with a move towards more consumption of high-value agricultural commodities. Additionally, where the Green Revolution was once supply-led, the current agricultural transformation is now largely demand-driven. These changes have had many implications, particularly for the markets. There is a need for more coordination and new roles for the government. The major drivers behind this transformation include rising income, urbanization and population growth, outward-oriented trade policy, and changes in foreign direct investment.

This agricultural transformation has introduced new linkages for the farmer and buyer relationship, due to the increasing preference for high-value commodities, which are generally more perishable. If the appropriate infrastructure is not in place, this can create increasing costs and losses throughout the supply chain. Torero introduced the paradox of the smallholders due to changes in agricultural production discussed above. Two issues are central to this paradox: changes in production methods are not scale neutral as they were during the Green Revolution, and economies of scale in agriculture may apply in the input supply, processing of harvests, and in transport.

Torero noted that there are several levels of problems that are faced by smallholders throughout the value chain. In production, primary concerns including the quality of inputs, low productivity, and non-demand linked production. In the supply chain, weak road infrastructure, lack of storage, and food waste and losses are of concern. Low processing, a lack of quality product, poor returns, and low capacity utilization are primary issues in the processing stages. Finally, in marketing, challenges include poor infrastructure, a lack of grading and linkages, and a lack of transparency in prices.

Torero noted that the four key issues he planned to address in his presentation included (1) the heterogeneity of small holders, (2) access to infrastructure, (3) resolving of market failures and obtaining economies of scale, and (4) scaling up of solutions.

Regarding the first issue of heterogeneity of small farmers, Torero noted that rural households in developing countries are extremely diverse in their economic characteristics. Rural development policies need to take this heterogeneity into account to be effective. Torero discussed the concept of the stochastic profit frontier and efficiency in terms of that frontier, which were used to develop a typology of development domains. This typology takes into

[24] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Maximo Torero (May 3, 2011).

consideration level of efficiency and potential, along with a poverty index that was used to assess policies that could improve productivity and efficiency. For example, for areas of low efficiency and high potential, with high levels of poverty, it is possible to identify policies that may improve efficiency throughout the value chain analysis. Torero noted that he has conducted research on ten countries using this type of analysis and is currently completing the empirical analysis.

Torero discussed his research to address problems related to access to infrastructure. Utilizing the concept of isoprofits in economics, he was able to account for costs in an analysis of the effectiveness of infrastructure investments. He used the example of maize grown in South Africa, first examining the yield in terms of production potential and infrastructure access. In his analysis, he was able to assess areas where it would be possible to have the highest potential in terms of returns.

Torero also discussed the lack of coordination of infrastructure services found in many countries. For example, in many developing countries, electricity may be managed by one ministry, while transportation issues may be overseen by another ministry, etc., with little coordination between these entities. Torero noted that examining the whole chain is imperative to understand how to improve coordination and infrastructure issues.

Regarding market failures and obtaining economies of scale, Torero discussed research examined various ways private companies are working with small farmers, including contract farming arrangements. He noted that there are barriers to vertical integration that make it desirable to contract out (e.g., land laws and need for flexibility). Torero cautioned that exploitation is possible when firms have monopsonistic power.

Torero noted that studies have found that regarding conventional contract farming arrangements, smallholders may be hesitant to enter into contract agreements, as the monitoring costs may be too high. Additionally small producers may not have resources to meet the quality specifications. There is also the risk of higher costs of production and contract defaults. For example, it has been shown that cash constrained farmers may break their contract because they may need cash sooner than is permitted by the contracts. To address these concerns, Torero discussed efforts to utilize microfinance options such as club formation, which could reduce costs for smallholders. Strengthening farmer association groups is another approach to improve contract arrangements with small farmers. Torero noted that IFPRI is now evaluating cases of contracts entered into with groups of farmer associations as compared with contracts with individual farmers to determine if there is any significant difference.

Regarding the scaling up of solutions, Torero discussed the use of impact evaluation and typology. Evaluation in particular can be used to identify and measure project results, identify a causal link between an intervention and these results, provide a systematic and objective assessment of program impacts, and could assist in determining if interventions are relevant and cost effective. Finally, evaluation can be used to promote accountability, evidence-based policymaking, and learning.

ECOSYSTEM MANAGEMENT[25]

Jeffrey Milder, EcoAgriculture Partners

Jeffrey Milder discussed approaches to ensure sustainable management of natural resources while expanding food production. As previously discussed, in the 21st century, society will place increasing demands on the world's rural land base. The challenge of "sustainable food security," therefore, is not solely about increasing global food supplies by approximately 70 percent in the context of climate change and growing resource scarcity. It is about doing so while simultaneously meeting other societal needs from agricultural lands—needs that include the provision of clean water and other ecosystem services to urban areas and other downstream users, mitigation of climate change by sequestering carbon, protection of biological diversity, and provision of energy for local use and/or world markets. Recent empirical and modeling studies suggest that it will be impossible to meet all of these objectives at regional to global scales if each is pursued through separate, single-objective strategies. Instead, integrated approaches to landscape management are needed to increase synergies among these multiple objectives and thereby generate larger bundles of goods and ecosystem services from rural lands.

Ecosystem management provides a theoretical and practical framework for the integrated management of agricultural landscapes. This framework seeks to balance resource conservation with resource use through a holistic approach that manages resources as systems rather than individual parts and that integrates scientific knowledge with social, economic, and political conditions and values.

While ecosystem management is rooted in the field of biological conservation and natural resource management, its principles are useful for supporting sustainable approaches to food production. At the farm scale, ecosystem management approaches can be used to increase yields profitability and sustainability by managing agricultural biodiversity (e.g., through integration of diverse crop varieties and non-crop species), conducting integrated pest management, and managing soils in ways that increase beneficial nutrient and water cycling processes. These basic principles are applied in a variety of agroecological farming systems including organic agriculture, agroforestry, permaculture, conservation agriculture, and systems of rice intensification.

Landscape scale applications of ecosystem management in agricultural areas ("ecoagriculture") have historically been less widely used than farm-scale application, but are likely to be increasingly important for supporting sustainable food production in the future. Ecoagriculture approaches may be needed both to address challenges to agricultural production (e.g., adaptation to climate change, management of upstream-downstream water dynamics, and resolution of land-use conflicts) and to capitalize on new opportunities (e.g., sequestering carbon in agricultural landscapes). In ecoagriculture landscapes, synergies among multiple landscape outcomes are realized through improved spatial planning and organization of land use, and deliberate management of ecosystem services to agriculture (e.g., pollination and pest control), as well as ecosystem services provided by agricultural areas, economies of scale achieved through collective action, substitution of natural capital for financial capital, and several other mechanisms.

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[25] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Jeffrey Milder (May 3, 2011).

A recent survey of ecoagriculture landscape approaches for achieving food production, natural resource conservation, and Millennium Development Goals identified five salient characteristics of such approaches (Milder et al., 2011):

1) Management is conducted at the scale of landscapes—areas of hundreds to thousands of square kilometers defined by common biophysical, socioeconomic, cultural, and/or jurisdictional characteristics, and often defined around specific management problems or challenges.
2) Landscapes are understood and managed as systems, in which multiple components interact dynamically in feedback loops.
3) Landscapes are deliberately managed to achieve multiple outcomes.
4) Adaptive management processes are used to conduct evidence-based decision making and create a structured process by which to learn from experiences.
5) Landscape management is conducted by multi-stakeholder groups supported by social learning.

Ecoagriculture-type approaches to managing agricultural mosaics have become more prevalent in recent years, driven by grassroots action, as well as new agency programs (e.g., investments in sustainable land management in Africa and elsewhere), new policy and governance platforms (e.g., various territorial development initiatives in Latin America), and new forms of investment. Hundreds of examples have been documented, representing all continents except Antarctica.

Key barriers to the more effective and widespread use of ecoagriculture include the lack of supportive governance structures and institutions, which are frequently not conducive to cross-sectoral, landscape-scale action. In addition, knowledge and capacities needed to manage landscapes for multiple objectives are not widely held, and "landscape literacy" is not commonly a part of university or adult education for agriculture and environment professionals, farmers, and community leaders. With some notable exceptions, incentive structures do not adequately encourage farmers and land managers to consider the value of ecosystem services and the effects of environmental externalities in their decision making processes. Future research on the adoption, effectiveness, and functioning of ecoagriculture approaches to landscape management can help expand the contribution of such management solutions to food security at local, regional, and global scales.

GENERAL DISCUSSION

Workshop participants and speakers discussed evaluation efforts and data quality issues during the discussion session. One participant noted that Mike Bushell, Maximo Torero, and Jeffrey Milder each discussed different criteria for evaluating agricultural programs and policies and asked if the speakers could recommend any standard evaluation criteria. Torero noted that initiating evaluation efforts after a program has already been designed and is the process of being implemented can be costly. He added that the key to effective evaluation efforts is to design these in conjunction with implementation planning rather than at the back end. Milder stated that from the standpoint of landscape and ecosystem management approaches, controlled experiments or research on the outcomes of those systems are not currently available and may not be appropriate due to the number of exogenous factors that cannot be controlled. Milder added that the goal of monitoring in these types of systems, rather, is to provide insight not only into food security issues but to understand the simultaneous implications for natural resources. Milder noted that in terms of designing projects effectively to address a community's needs, it is important to examine all important factors up front so that these are accounted for in the initial planning stages. CARE, an international aid organization, recently developed frameworks for working with communities on climate change, adaptation and vulnerability and discussed these issues upfront with the community so that they could be integrated into the design of a project. Milder added that in thinking about the smallholder context where adaptations to environmental change are the cornerstone of sustainability, one method for evaluating efforts could be to assess the capacities the communities have to adapt to changing circumstances. Human capital should not be ignored as a legitimate outcome of programs and investments.

Regarding data, one participant noted that data should be accurate, timely, objective, sustainable, comprehensive, flexible, and be able to measure change. The participant added that nonsampling errors are a significant issue, as is data objectivity. Torero noted that a significant challenge in collecting data is the reliance on census data that in some cases may be 10 to 15 years old. The funding to update these data is also lacking. One participant stated that the Gates Foundation is currently funding a project in Ethiopia that uses satellite imagery to collect census data. Pardey added that alternative technology can provide new and innovative approaches for obtaining much needed and accurate data.

REDUCTION OF YIELD GAPS TO INCREASE PRODUCTIVITY AND SUSTAINABILITY[26]

Judith L. Capper, Washington State University

Judith Capper discussed barriers to sustainably increasing the productivity of crop yields to meet rapidly increasing global food demand. She noted that projections indicate that the average domestic income will increase, with the projected GDP of China and India being similar to that of the United States (Keyzer et al., 2005). Compounding the increased demand, the desire for a diet richer in animal-source proteins rises in tandem with increasing income, thus the global livestock sector will be charged with the challenge of producing more milk, meat and eggs using fewer resources.

On a global basis, crops yields have increased over time as knowledge and understanding of plant nutrition and management has improved, innovative agronomical practices have been implemented, and technologies have been adopted. Between 1961 and 2010, the global corn yield increased from 1.94 t/ha to 5.98 t/ha. If the same trend continues until 2050, corn yield will reach 7.78 t/ha (extrapolated from FAO data [http://faostat.fao.org]). Malnutrition and hunger are significant issues across the globe, with 925 million people undernourished annually and 16,000 children dying from malnutrition each day (Food and Agriculture Organization of the United Nations 2010). Nonetheless, it has been suggested that the quantity of food produced is already sufficient to feed the population; therefore the issue is not one of production but of a combination of considerable food wastage and the lack of designated infrastructure to transport food to those

[26] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Judith Capper (May 3, 2011).

areas of the world where it is currently lacking (Rabobank Group, 2010). If this conflict was overcome by the year 2050 and crop yields continued to increase, food security might cease to be a significant issue.

Capper discussed public perceptions on food choice related to organic and genetically modified foods. The demand for organic food products is increasing in developed countries where malnutrition is more often associated with obesity than undernourishment, and consumers have sufficient income to demand food choice. In the United States, organic food commands a small portion of total market share (3.7 percent; Organic Trade Association, 2010) with the greatest share being seen in the fruit and vegetable sector (~12 percent), compared with dairy (~ 6 percent; Organic Trade Association, 2011) or beef (2.5 percent; Clause, 2010). Recent data shows that almost 95 percent of U.S. consumers buy food according to economic, nutritional and taste aspects, with only 4 percent seeking food according to their specific lifestyle choices (e.g., vegetarian, organic or local), yet a majority of consumers will occasionally buy organic food (Simmons, 2011). A survey by Raab and Grobe (2005) reported that consumers associated organic foods with positive attributes including “chemical-free,” “healthier/more nutritious,” “clean/pure” and “earth-friendly,” whereas the main negative attributes were related to economic cost and a mistrust or lack of knowledge of the practices associated with organic production.

Capper argued that although the generally positive consumer response to organic food production improves the social component of the sustainability triangle (economic viability, environmental impact and social acceptability), productivity is demonstrably less in organic systems. Crop yield data gathered from the 2008 U.S. organic production survey (USDA/NASS 2010a) documented reductions in major crop yields varying from 29 percent for corn grain to 34 percent for soy and 40 percent for winter wheat. In a world where arable land sufficiency is decreasing, this presents a significant concern if future food security is to be maintained. By contrast, the adoption of genetically modified (GM) crops led to a 12.3 million ha reduction in the amount of total land required for canola, cotton, soy and corn production in 2009 (Brookes and Barfoot, 2011).

Public perception of organic food as being “chemical-free” and “clean/pure,” stated Capper, is supported to some extent by the prohibition of inorganic fertilizers and conventional pesticides in organic production; however, it should be noted that many naturally-derived chemicals are approved for use as organic pesticides. Organic production has greatly advanced the ability of producers to control pests through non-chemical means; however, this effect is not confined to alternative production systems.

On the other hand, Capper noted that public perception of GM foods has generally been negative, which has impacted GM food production. However, using biotechnology to improve disease and pest resistance reduced pesticide spray use on GM crops by 8.7 percent between 1996 and 2009, thus reducing the environmental impact from pesticide use by 17.1 percent (Brookes and Barfoot, 2011). The global acreage devoted to GM crops is estimated at ~10 percent of cropland; therefore, the reductions in pesticide use resulting from biotechnology do not negate the concerns relating to widespread chemical use in conventional production. Nevertheless, the data indicate that both technological and organic approaches show promise in reducing pesticide inputs to crop production.

In contrast to organic practices, which often require increased passes across the crop to mechanically control pests, use of GM crops has favored the adoption of reduced-tillage practices, which have a two-fold advantage with regards to the environmental impact of crop production. Fuel use decreases in reduced-tillage practices as a consequence of the lesser intensity of cultivation compared with conventional tillage. Furthermore, the quantity of carbon sequestered into the soil is increased under reduced-tillage systems. Brookes and Barfoot (2011) estimate the reduction in carbon emissions conferred by GM-crop adoption to be equal to removing 7.8 million cars from the road per year.

The environmental impact mitigating effects of improved productivity are not restricted to crop production, but also offer opportunities for considerable gains within livestock production. Within the U.S., advances in nutrition, management and genetics between 1944 and 2007 conferred a four-fold increase in the average milk yield of dairy cattle and facilitated the production of considerably more milk (84.2 billion kg 2007 vs. 53.0 billion kg 1944) from a national herd containing 64 percent fewer animals (9.2 million cows vs. 25.6 million cows). Carbon emissions per unit of milk were reduced by 66 percent over the same period, with an industry-wide decrease of 41 percent in total emissions (Capper et al., 2009). The same trends can be seen on a global basis at a single time point. A recent FAO report modeled GHG emissions from dairy production using life cycle analysis, demonstrating that as production intensity increases and the average milk yield shifts from approximately 250 kg/cow for Sub-Saharan Africa to ~9,000 kg/cow for North America, the carbon footprint decreases from 7.6 kg CO_2-eq/kg milk to 1.3 kg CO_2-eq/kg milk. If we examine yield data for organic dairy production in the USA, conventional milk yields are significantly higher (10,062 kg/yr) compared with yields from organic (7,425 kg/yr) or grazing herds (7,213 kg/yr; USDA 2007). This decline in productivity has a significant effect upon resource use. Capper et al. (2008) modeled the effect of supplying the entire projected U.S. population in 2040 with the 0.71 liters of milk (or its low-fat equivalent) per day as recommended by USDA (2005). Assuming that current productivity trends continue for both crop and animal production, fulfilling dairy requirements via organic production would increase the national herd size by 3.5 million animals (20 percent) compared with conventional production and augment land requirements by 3.1 million ha (a 30 percent increase). The world record for dairy production is currently held by a Wisconsin dairy cow that produced 32,726 kg of milk over 365 days in 2010. Given that the average U.S. cow produced 9,593 kg of milk in 2010 (USDA, 2011), considerable progress can continue to be made in order to improve productivity and reduce environmental impact.

Yield thresholds for meat production relate to the quantity of edible protein produced per animal (i.e., the slaughter weight and the proportion of the carcass that is meat vs. non-edible by-products). Anecdotal evidence from the beef processing industry indicates that a threshold for beef-animal slaughter weights has been reached and that slaughter weight cannot continue to increase without reorganization of the processing infrastructure, currently designed for an upper threshold of approximately 635 kg (average U.S. beef slaughter weight for 2010 was ~590 kg). Nevertheless, the beef industry has a considerable opportunity to improve productivity through improving both growth rate and lean muscle accretion through the use of technologies that improve feed efficiency and partition nutrients towards muscle growth. Such technologies include ionophores, steroid hormone implants, in-feed hormones and beta-agonists. These technologies are not permitted within organic production, leading to efficiency losses.

Fernàndez and Woodward (1999) compared performance parameters for beef animals finished in organic or conventional feedlot systems and reported decreases in growth rate and feed efficiency (1.40 kg/d and 7.57 kg feed per kg gain for the organic system, 1.77 kg/d and 5.44 kg feed per kg gain for the conventional system), leading to a reduced slaughter weight 536 kg vs. 578 kg), increased days in the feedlot (226 d vs. 164 d) and an increase in total production costs of $0.51 per kg gain ($1.86/kg gain vs. $1.35/kg gain), a cost that would ultimately be passed to the consumer. This comparison is somewhat disingenuous, as feedlot finishing is not routinely practiced within organic production--grass-fed finishing systems (without the use of productivity-enhancing technologies) are far more common. As a consequence of the reduced nutrient density of forage-based diets, productivity indices in grass-fed systems are reduced still further, with growth rates averaging 0.59 kg/d over the entire lifespan compared with 1.74 kg/d. If the quantity of U.S. beef produced in 2010 was supplied from a grass-fed system, an extra 64.6 million animals would need to be added to the national herd, the extra land needed would be equal to three-quarters of the land area of Texas (53.1 million ha), and the extra water required would be sufficient to supply 46.3 million U.S. households for a year (adapted from Capper, 2010). Despite the popular perception that organic systems are more environmentally-friendly, the increase in greenhouse gas emissions produced by changing to a grass-fed system would be equal to adding 26.6 million cars to the road per year.

Nutritionally, studies show that grass-finished beef contains higher quantities of beneficial omega-3 and conjugated linoleic acids. The concentrations are extremely small, and their advantages may be outweighed by a higher concentration of saturated fatty acids, which have negative health effects (Leheska et al., 2008). Nonetheless, the social acceptability of a pasture-based system that is more akin to consumers' perception of a "natural" environment and diet for cattle gains significant kudos when compared with the public image of a contemporary feedlot.

Capper stated that one significant advantage of organic production from a consumer perspective is the prohibition of antibiotic use in livestock production. Despite the considerable debate as to whether antibiotic use in animals has significant implications for human health, evidence suggests that, when specifically asked, consumers consider it to be a concern (Wenderoff, 2011). Reviewing 31 published studies comparing organic and conventional systems reveals that there was no difference in the prevalence of antimicrobial resistance (AMR) between systems in nine studies, whereas organic systems showed a lesser prevalence than conventional systems in the remaining 22 studies (Alali et al., 2010; Call et al., 2008; Jacob et al., 2008; Walid et al., 2010; Wilhelm et al., 2009; Zhang et al., 2010). Removal of antibiotic technologies from livestock production certainly has the potential to mitigate AMR; however, it is important to note that none of the studies reported zero AMR in organic systems.

Simmons (2011) showed that a small yet vocal proportion of consumers (1.7 percent) regard the majority of food purchasers as being naïve and regard it as their responsibility to educate them about the perceived dangers of contemporary large-scale food production. The preponderance of information that condemns technology use in food production is overwhelming and may mislead the consumer. For example, a recent editorial in the Washington Post mentioned GM corn and soy, cloned animals and McNuggets™ in the same sentence, conferring the message that cloned animals are as ubiquitous as fast food restaurants. However, Then and Tippe (2010) report that 600 cloned cattle exist in the USA and 120 in Europe. When compared with the 2010 U.S. cattle population of 93.7 million animals (USDA/NASS, 2010b), the numbers are extremely small, yet media reports play upon consumer fears and misconceptions to incite a climate of fear regarding the use of technology.

Capper noted that the beauty of consumer choice lies in the fact that there is a market for every production system, intensive or extensive, large-scale or small-scale, contemporary or alternative, with or without technology use, providing that it continues to adapt to the economic, environmental and social issues that together confer sustainability. Although organic production systems confer positive advantages in terms of social sustainability, productivity losses lead to an increased environmental impact and economic impact compared with conventional systems that use technology. In order to fulfill the dietary requirements and desires of the growing population it is essential to improve productivity within all systems without demonizing or idolatrizing particular systems or practices. Using the system-specific sustainable practices should ensure that consumer choice is maintained without prescription of a one-size-fits-all solution.

ENERGY EFFICIENCY AND FOOD SECURITY FOR ALL--THE IMPACT OF FERTILIZER[27]

Donald Crane, IFDC

Donald Crane discussed the use of fertilizers, energy efficiency, and implications for food security. Technologies to increase efficiencies in fertilizer production and use in well-managed cropping systems on existing arable land will be required to meet the challenges facing agriculture as the world's population increases. Future technologies must address the energy constraints and environmental challenges in the production and use of fertilizers and define where increases in energy and nutrient use efficiencies can occur. New technologies must support intensification while reducing the environmental footprint of farming systems. At present, crops utilize only 40 percent or less of the applied nitrogen (N) in developing countries and approximately 60 percent in developed countries; thus N losses are significant. Losses of P and K fertilizers are generally much less. Assuming current conditions continue, a steep upward trend in the demand for N fertilizer is predicted by the IFDC FertTrade model based on scenarios generated from IFPRI's IMPACT model (Figure 3-2). However, there are a variety of mitigation factors that could significantly impact N fertilizer consumption, including extensive adoption of current technologies such as the 4Rs (right source, time, place and rate), integrated soil fertility management (ISFM utilizes all available organic inputs, inorganic fertilizers, and soil amendments) and nutrient recycling. Based on information gathered from peer reviewed journals and industry and third party publications, strategies and adoption timelines to develop and introduce new "smarter and greener" and cost-effective fertilizer products, biotechnology to improve N use efficiency and biological N fixation into grain crops were also evaluated. Three factors (adoption rates, crops and cropping zones affected, and commercialization time frames) related to each innovation impacted the final outcome of these curves. Slope was impacted by adoption rates assumed by IFDC's best estimates. The crops and geographical areas where the new technologies would be utilized impacted the weighting of the slopes. The introduction and phasing in of the new technologies dictated the timeframes (e.g., Arcadia Biosciences Inc. claims the first introduction of new NUE crops to be in 2020). Results indicated that success in implementing these "new" strategies combined with current technologies could produce the required increase in food production with little increase in N fertilizer use.

[27] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Donald Crane (May 3, 2011).

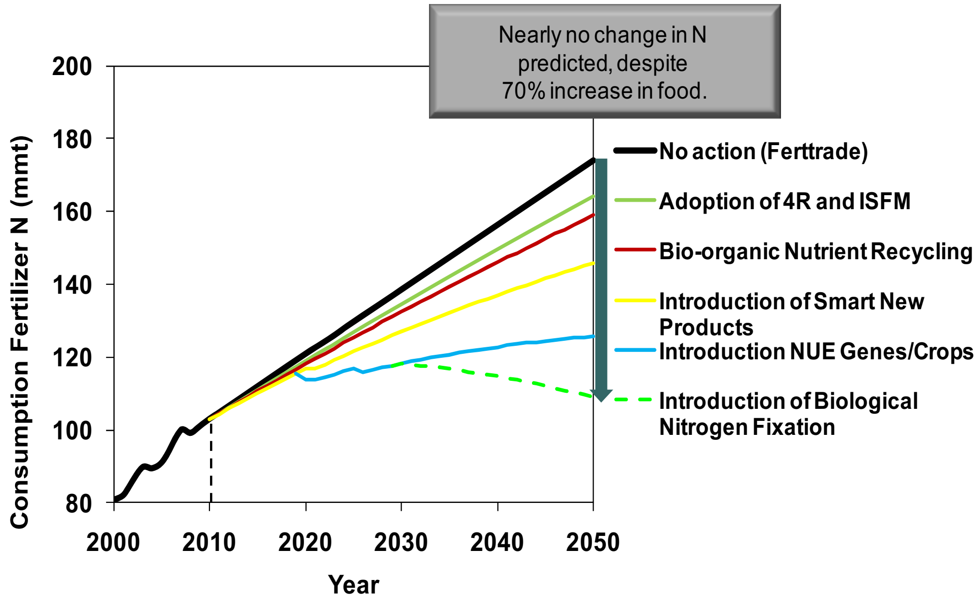

FIGURE 3-2 IFDC FertTrade model
SOURCE: Presentation by Donald Crane, IFDC, May 3, 2011.

There is a high correlation between new technologies that improve N use efficiencies and energy conservation (Figure 3-3). Fertilizer production accounts for approximately 1.2 percent of the global energy consumption, with N fertilizer production being the largest component. Average global N production requires six times more energy than P production and five times more energy than K production. The most energy-intensive N product is ammonia (NH_3), which forms the basis for all other industrial N. Theoretically, energy consumption in fertilizer production could be reduced up to 40 percent through worldwide adoption of modern production methods. Virtually all of the NH_3 produced utilizes the Haber-Bosch process, in which the H_2 donor is natural gas, coal or naphtha. Switching to cleaner sources of H_2 would provide CO_2 emission reductions but likely no change in energy use. However, H from cleaner sources is not yet economically viable. Assuming the status quo and recognizing that the energy curves are derived from N use curves (Figure 3-2), the FertTrade model output projects a steep increase in energy use for N production and use. Widespread adoption of current best management practices (4Rs, ISFM, etc.) and recycling would reduce energy consumption by approximately 15 percent. Considering the energy savings based broadly on reduced N production and the energy penalties associated with the introduction of each "new" technology, energy consumption in 2050 could be less than half of the "no action" scenario and only 10 percent higher than current consumption. Other possible but longer-term research and technology development options include non-Haber-Bosch electrolytic and homogeneous catalytic processes that may eventually lead to NH_3 production at room temperature and atmospheric pressure and that have the potential to stabilize energy consumption at current levels.

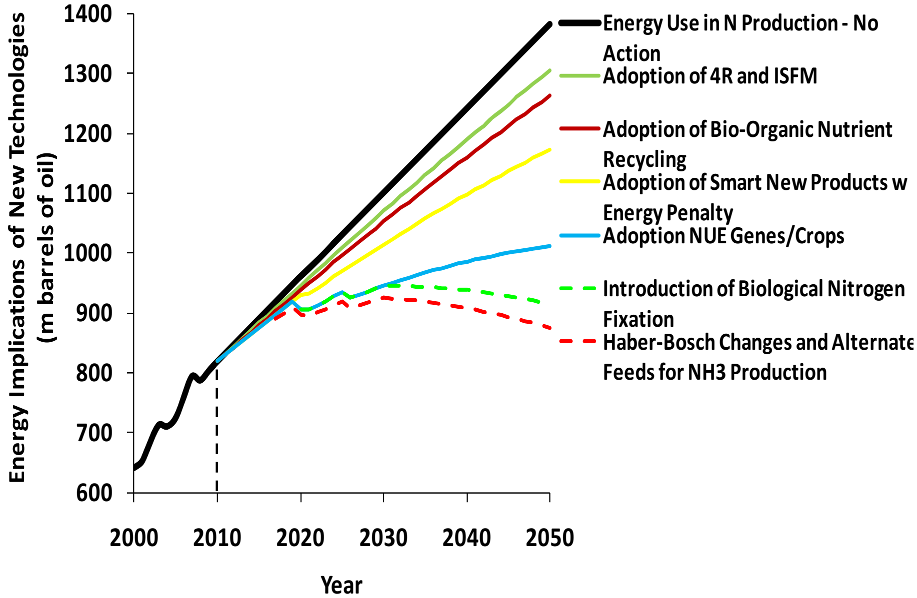

FIGURE 3-3 N Energy Slide
SOURCE: Presentation by Donald Crane, IFDC, May 3, 2011.

The energy profile of P and K fertilizers compared with N reflects a reduced proportion due to raw material and processing and an increased proportion due to logistics. P and K are finite resources. Thus it is important to consider the use of non-conventional sources of P and K. For example, Crane noted that work being conducted at IFDC seeks to render usable P rocks previously considered unsuitable for P fertilizers. In order to preserve P and K natural resources and reduce environmental impact, we must invest in increasingly efficient mining and processing, recovery of phosphates from fine wastes, and various fertilizer modifications. Additionally, there are three main areas for improvement to P and K use efficiency. These include new and different products or formulations, changes or modifications to soil properties and possible genetic modifications to plants that can enhance the P and K uptake.

Current estimates indicate that agriculture contributes up to 12 percent of total global greenhouse gas (GHG) emissions, of which only about 2.5 percent comes from fertilizer production and use. Unfortunately, another 6-17 percent of GHG emissions come from land conversion (Flynn and Smith, 2010; Jenssen and Kongshaug, 2003). Emissions associated with fertilizer production are primarily attributed to the initial production of NH_3. For every ton of NH_3 produced, about two tons of CO_2 are produced. If cleaner H sources could be identified, annual emissions of CO_2 to the atmosphere could be reduced by 200 million metric tons. Although efficiencies in fertilizer production can result in CO_2 emission reductions, mitigation strategies to prevent agricultural land expansion have much greater potential to reduce emissions (Figure 3-4). Based on the current rate of land expansion, IFDC projects that GHG emissions could increase in excess of 10 billion mt CO_2-eqv by 2050. The “no action” or “status quo” scenario generated by the FertTrade model projects a doubling of GHG emissions from the year 2000 levels by 2050. However, adoption of current best management practices combined with phased-in adoption of expected “new” technologies are projected to reduce agriculture contribution to GHG emissions to current levels by 2050. The most important point to recognize in Figure 3-4 is that reduction of GHG emissions resulting from preventing land expansion for crop cultivation (agricultural extensification) dwarfs all GHG emissions reductions generated by new technologies and innovations while simultaneously providing global food security through agricultural intensification. However, widespread adoption of cost-effective, accessible and user-friendly "new" technologies and innovations relative to current technologies (including fertilizer options) should facilitate a rapid reduction in agricultural extensification.

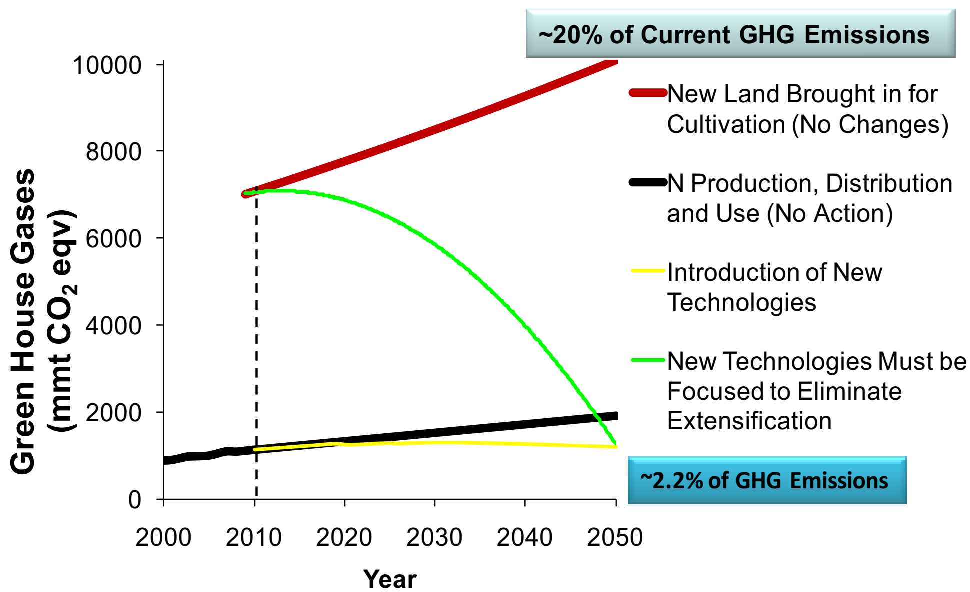

FIGURE 3-4 N CO2 Slide
SOURCE: Presentation by Donald Crane, IFDC, May 3, 2011.

Clearly, a global approach to becoming more energy efficient in future agricultural production is required. As natural resources such as land and water become scarcer and the demand for food and energy grows, it will take a concerted effort by agronomists, plant geneticists, chemists, engineers, economists, and a broad spectrum of other disciplines, working in concert, to develop the solutions to feed the world, minimize energy use and environmental impacts. To help address these challenges, the IFDC recently launched the Virtual Fertilizer Research Center (VFRC). The VFRC's mission is to ensure that "the world's smallholder farmers have ready access to sustainable, affordable, efficient and environmentally friendly fertilizer technologies."

GENERAL DISCUSSION

During the discussion session, several participants inquired about challenges related to N and P use efficiency and efforts to address these challenges. One participant stated that fertilizer efficiency could be improved by several practices not discussed previously in Donald Crane's presentation, including crop enhancement chemicals that have been shown to improve nitrogen use efficiency and agronomic practices such as tillage, crop rotation, and cover crops, all of which might have an immediate impact on efficiency. Another participant noted that there are organizations already in the process of funding this type of work, including the Gates Foundation.

Another participant inquired as to who is currently conducting research to produce the needed fertilizer products and application methods. Crane noted that there is currently limited R&D investment in this area, adding that the principle reason for this is that what is currently being sold are commodities, and there is a good deal of investment that already exists in these processes, so there is little incentive for breaking this paradigm. Crane added that as discussed above, his organization is establishing the Virtual Fertilizer Research Center, which will be used to work with the broader research community to initiate this type of research.

One participant asked whether a "sustainable diet," based on raw materials from high-productivity agriculture, could be synonymous with a healthy diet. The participant noted that a study recently released by the British Food Standards Agency found that diets based on conventional food were no more or less healthy than those based primarily on an organic diet. Judith Capper agreed that the data have not been conclusive as to whether a conventional or organic diet is considered healthier and suggested that more research should be done on this issue. Capper went on to note that there is a need to educate consumers about these issues. However, this issue was not a focus of the workshop.

PRIVATE INVESTMENT AND FARM SIZE ISSUES[28]

Derek Byerlee, Independent Scholar

Derek Byerlee discussed the role of private investment and large scale farming in global food security, with particular respect to developing countries. Several years of strong agricultural commodity prices have translated into rising demand and prices of farmland. Expansion has been concentrated in Sub-Saharan Africa, Latin America, and Southeast Asia. Key commodities driving this expansion were oil crops, especially soybean, sugar cane, rice, maize, and plantation forests. Expanded trade in agricultural commodities has led to shifts of production to countries, such as Argentina and Brazil, with potential to increase their crop area, in order to meet booming demand from China and other emerging economies. Traditionally, farmland prices in emerging economies such as Brazil and Argentina were low relative to land of comparative quality in high-income countries, but that gap has been closing. The land rush of recent years is unlikely to slow. Between 120 million ha and 240 million ha of additional land will be needed by 2030, depending on assumptions about trade, biofuels, and demand.

A conservative estimate of available land with medium-to-high potential that could be converted to crop production is about 450 million ha—that is, land that is non-forested, is non-protected, and has a population density of less than 25 persons/km^2. This is equivalent to one-third of currently cropped land (1.5 billion ha). More than half of this area is located in seven countries (Sudan, Brazil, Australia, Russia, Argentina, Mozambique, and Democratic Republic of Congo), although often far from ports and roads.

The recent rise in demand for farmland has been associated with increasing interest by corporate investors and investment funds in production agriculture. Traditionally, agriculture worldwide has been associated with family farming in which the owner and his or her family manages and provides most of the labor. This is true in both poor and rich countries, although average size of a family farm varies widely from around 1 ha in much of Asia to 178 ha in the

[28] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Derek Byerlee (May 3, 2011).

USA (Eastwood et al., 2010). The main reason is that agricultural production has few technical economies of scale, implying that a range of production forms can coexist.

The 2009 World Investment Report estimated foreign direct investment inflows into businesses with primary agricultural production as a core activity of about $7 billion in 2007, all in developing countries. Press reports suggest that the 2008 commodity boom attracted many new investors into agriculture. According to these reports, out of a reported 57.8 million ha of land demanded globally in 2008-9 by foreign investors, 39.7 million were in Africa. On the ground verification estimated land acquisitions were much lower than stated in media reports, and in the vast majority of cases, investors utilized only a fraction of the land acquired.

Associated with growing investment in domestic and foreign farming has been a dramatic rise in the size of some farming operations. The largest crop-based farms in the world are now in emerging economies where many "superfarms" control hundreds of thousands of hectares, and the largest are now approaching a million ha of good crop land and sales above $1 billion annually. These companies focus on Brazil, Argentina, Russia and Ukraine, and Southeast Asia, producing grains, oilseeds, sugarcane and palm oil.

Developments in technology—such as large machinery, zero tillage, GMOs, and information and satellite technology—have made it easier for companies to manage very large farms. But true "superfarms" have emerged only where imperfections in other markets, especially marketing and access to finance, provided advantages to large operations well beyond the production stage. In an undistorted policy environment, owner-operated farms, which may be linked to processors via contracts, continue to be the pillar of production agriculture, including in high-income countries. At the same time, experiences in Latin America and Eastern Europe have shown that with advances in technology and new business models, very large farms can overcome diseconomies of scale and can be globally competitive, even for non-plantation crops such as grains and oilseeds. The largest companies, many of them traded publicly, are vertically integrated into input supply and output markets and operate across several countries.

The growing private sector interest in agriculture presents a major opportunity for developing countries to capture much needed access to capital, modern technology, and new markets to spur agricultural growth and employment. It might also be argued that the rapid expansion of large farms has contributed significantly to global food supply. Half or more of the increase in exports since 1990 of vegetable oils, grains oilseeds, and sugar has been generated through expansion of large commercial farms. Without this, prices of some commodities in high demand by China and other emerging markets, such as palm oil and soy, might be even higher today.

However, impacts on food security in terms of access to food have in many cases been negative. Where land tenure is not well defined or land governance is subject to corruption, investments have often infringed on the rights of traditional users, without compensation. Large land transactions were often not well recorded, lacked transparency, and did not adequately consult with local communities. These problems were most severe in Sub-Saharan Africa where formal land markets and land titling are generally absent. Such transfers often reduce tenure security to local communities, threaten local livelihoods, and increase the likelihood of food insecurity and conflict. A growing number of examples of such negative outcomes have led to the recent outcry about "neocolonial landgrabs."

Emphasis on large farms also risks growing inequality in land ownership with negative consequences for broad-based rural development and future growth. Farmland ownership and operation is now highly concentrated in several countries of Eastern Europe and in central-western Brazil. Environmental concerns have also surfaced, especially where land expansion occurs at the expense of tropical forests, as with pastures in Latin America and oil palm in Southeast Asia. Finally, even economic benefits are often compromised by lack of technology and land speculation—especially where land is provided through government channels free or at very low prices. For all these reasons, investments in Africa often fail, with lasting damage to communities and the environment.

Byerlee said that, to realize the benefits that could be attained, changes in land governance, policy, and institutional capacity will be needed. These changes include recognition of local rights, transparent mechanisms to transfer rights voluntarily instead of having them expropriated by the state, and public institutions with clear mandates and sufficient capacity to prevent negative social or environmental effects. Additional provisions for local employment content, training and technology transfer would help spread the benefits. Although this appears a daunting list, there are good examples to draw from that indicate that the benefits from implementing these reforms could be high. As expected, outcomes are best where investments are made in situations of good land governance where property rights are already well defined.

Private investment in farming will be critical to ensuring agricultural supply response for world food security. A variety of institutional models that involve a range of farm sizes will be needed. The first priority is to level the playing field to ensure that commercially-oriented family farms can respond to improved incentives and tap new sources of private capital. Much greater attention to land rights and governance will be needed to ensure favorable outcomes in Sub-Saharan Africa.

LOSSES AND WASTE IN THE FOOD SUPPLY CHAIN[29]

Adel Kader, University of California, Davis
(Presented by James Gorny, U.S. Food and Drug Administration)

James Gorny, presenting on behalf of Adel Kader, discussed the issue of waste in the food supply and strategies for reducing these losses. Postharvest losses and waste in foods of plant origin between the production and consumption sites are estimated to average about 33 percent and range from 5 percent to 50 percent, depending on the product's perishability and handling conditions during domestic and export marketing. Reduction of these losses can increase food availability to the growing population, decrease the area needed for food production, and conserve natural resources.

Strategies for loss reduction include use of cultivars with longer postharvest life, use of an integrated crop management system that maximizes yield and quality, and use of proper postharvest handling procedures to maintain quality and safety of the products. Although reducing postharvest losses of already-produced food is more sustainable than is increasing production to compensate for these losses, less than 5 percent of the funding of agricultural research, extension, and development internationally is allocated to reducing postharvest losses and waste in the food supply chain.

Biological (internal) causes of deterioration include respiration and associated metabolic rate, ethylene production and action, rates of compositional changes (associated with color,

[29] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Adel Kader (May 3, 2011).

texture, flavor, and nutritive value), mechanical injuries, water stress, sprouting and rooting, physiological disorders, and pathological breakdown. The rate of biological deterioration depends on several environmental (external) factors, including temperature, relative humidity, air velocity, atmospheric composition (concentrations of oxygen, carbon dioxide, and ethylene), and sanitation procedures. Insect infestation, birds, and rodents are also important factors in losses of agronomic food crops (cereals, grains, oil seeds, and other dried products).

Although the biological and environmental factors that contribute to postharvest losses are well understood and many technologies have been developed to reduce these losses, they have not been implemented, in many cases, due to one or more of the following socioeconomic factors: (1) predominance of small-scale producers and handlers; (2) inadequate marketing systems; (3) inadequate storage and transportation facilities; (4) unavailability of needed materials, tools, and/or equipment; (5) lack of information; and (6) unintended consequences of some governmental regulations and legislations.

Strategies for reducing losses and waste of agronomic food crops include (1) drying to reduce moisture content to below 8 percent, (2) effective insect disinfestation and protection against reinfestation, (3) storage temperature (storage potential doubles for every 5ºC reduction in temperature), (4) maintaining storage relative humidity in equilibrium with moisture content of the product, and (5) proper sanitation procedures to minimize microbial contamination and avoid mycotoxin formation. The presenter suggested that international development organizations and governments should give highest priority to improving storage facilities of agronomic food crops at the national, regional, village, and household levels in all developing countries.

Availability and efficient use of the cold chain is much more evident in developed countries than in developing countries. Unreliability of the power supply, lack of proper maintenance, and inefficiency of utilization of cold storage and refrigerated transport facilities are among the reasons for failure of the cold chain in developing countries. Cost of providing the cold chain per ton of produce depends on energy costs plus utilization efficiency of the facilities throughout the year. Strategies reducing postharvest losses and waste of perishable foods in developing countries include (1) application of current knowledge to improve the food handling systems and assure food quality and safety; (2) removing the socioeconomic constraints, such as inadequacies of infrastructure, poor storage facilities and marketing systems, and weak research and development capacity; and (3) overcoming the limitations of small-scale operations by encouraging consolidation and vertical integration among producers and marketers of each commodity or group of commodities.

Following are some examples of the recommended loss reduction interventions: (1) improved containers to better protect produce from damage; (2) providing shade to reduce temperature and provide a natural source of cooling; (3) improved curing of root and tuber crops; (4) use of water disinfection methods and other sanitation procedures; (5) use of cost-effective cooling methods, such as evaporative forced air cooling, hydro-cooling with well water, and small-scale cold rooms with CoolBot-controlled air conditioners[30]; (6) effective insect control (disinfestation and protection against reinfestation); and (7) improved small scale food processing methods.

[30] The CoolBot works much like a cooler compressor and can be used with a window-type air conditioning unit to enhance its cooling capacity. It has proved particularly useful for farmers and florists.

GENERAL DISCUSSION

Emmy Simmons introduced the session by inquiring as to which of the low-cost methods described in James Gorny's presentation would be most effective in reducing global food waste. Gorny responded that there is no "silver bullet," but the methods he presented, including efforts to packaging materials, shading of produce, and transportation improvements, appear to be the simplest, least costly, and most easily implemented. Uzo Mokwunye added that little research is being conducted on postharvest losses, which is major issue in Africa, noting that for farmers with little income and small farms, building a silo, improving irrigation and refrigeration are not possible. Gorny agreed that it is not appropriate for small farmers to make a large investment in improving infrastructure, but noted that governments or individual companies could play a role in developing a cooperative approach to addressing some of these postharvest loss issues.

One participant inquired as to what farm structures may look like 25 years from now in the three relevant geographies of China, India and Africa. Derek Byerlee speculated that in China, in particular, farm population is declining and there will likely be farm consolidation, but how this will occur is unclear. With more entrepreneurial farmers expanding through land rentals, he noted that there may be an increase in the number of professional farm managers including private companies. Byerlee noted that Africa is the least certain and that clearly "smallholders are going to be the way forward."

Regarding investment in small farms, one participant inquired if public and private investments will likely materialize. Byerlee noted that there is currently significant interest from the private sector in agriculture; however, it is unclear how these investments will be implemented and whether they will be concentrated in contract farming or in other approaches. Recent public private partnerships on irrigation have demonstrated that there can be innovative approaches from both sectors for investing in agriculture.

Responsible investment issues were also discussed, as one participant noted, most governments are interested in attracting foreign investment. Kostas Stamoulis noted that country investment principles have been developed by the FAO, World Bank, International Fund for Agricultural Development, and United Nations Conference on Trade and Development. These principles, which provide a code of conduct for foreign investment, have been warmly received by the private sector, and there has been consultation with the private sector and the agencies that developed these principles. Although these agencies have offered to advise governments on the principles, there has not been interest from government agencies regarding how to handle negotiations on investments that respect land rights, the environment, etc. The private sector in this case is more eager to buy into these voluntary rules and principles than are some of the governments.

GLOBAL GOVERNANCE OF NATURAL RESOURCES: QUANTITY VS. QUALITY[31]

Nancy McCarthy, FAO

Nancy McCarthy discussed global governance of natural resources. Preliminary research on existing international agreements concerning natural resources reveals the large quantity and

[31] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Nancy McCarthy (May 3, 2011).

large variety in instruments and resources covered. Considering bilateral and multilateral treaties, agreements, and conventions, the international community has created thousands of instruments covering every resource type. These instruments vary greatly in language and scope, requiring a more detailed look at factors that make each successful or not.

McCarthy presented on her review of the nature of supra-national governance structures for natural resources important to food security. This review focused mainly on resources where externalities arise in resource use and management, in particular plant genetic resources, fisheries, water basins, forests, grasslands, and soil.[32] Once countries decide to draft agreements to manage these externalities, they face a number of choices in the design of those agreements.

Externalities give rise to the need for collective action--they determine the necessary membership in collective action agreements as well as the distribution of costs and benefits both from remaining at the status quo and from agreements to internalize externalities. The nature of externalities--positive and negative--strongly influences the costs of crafting and enforcing international agreements. For instance, ocean fisheries are an open-access resource with strong incentives for fleet owners to not comply with any agreements, especially with respect to species with high commercial value. Management of ocean fisheries implies all countries should be parties to agreements.

Further, it is very difficult to monitor highly mobile ocean fish stocks, making determinations of non-compliance difficult. Fish stocks accessed by a smaller number of countries in seas, lake, and rivers are more akin to a common pool resource, but similarly, difficulty in monitoring means that countries face high costs of ensuring compliance by their own nationals, especially with respect to high value species. On the other hand, agreements to invest in public maintenance for navigation on rivers generally present a far less formidable incentive structure. First, such agreements generally entail few countries. Additionally, public investments do not imply restrictions on their own nationals, so countries do not have to enforce compliance against their own citizens. Agreements on forest resources often focus on mitigating negative externalities (reducing deforestation on riparian land to reduce erosion and siltation) and on providing positive externalities (afforestation and reforestation to improve water flow and quality, to preserve biodiversity corridors). These agreements are generally between relatively small numbers of countries, and monitoring is easier than it is with fisheries, especially with satellite imagery. However, countries must still be able to ensure compliance by their own nationals, which may be costly. These examples demonstrate that the management of different natural resources implies different incentive structures, with implications for the design of agreements and the potential costs of monitoring and enforcement.

Once a set of countries has decided to enter into an agreement covering natural resources, several design elements come into play during negotiations. One issue is whether to craft a legally binding or non-binding agreement. Legally binding agreements are generally viewed as more credible than non-binding agreements, but non-binding agreements are seen as more flexible. Flexibility is often important when future costs and benefits are uncertain and where countries exhibit substantial heterogeneity, which can require flexibility in implementing the spirit of the agreement. Also important is the strength of domestic interest groups, which tend to strongly favor binding agreements and put less emphasis on the need for flexibility. On the other

[32] Air pollution can affect food security both directly and indirectly through climate change. However, this differs from the other resources, since air quality is affected (mainly) by non-resource-based sources (e.g. industries, transportation, etc.). There are still lessons to be learned from agreements such as the Kyoto Protocol and the Montreal Protocol, but these have been extensively studied elsewhere and so are not part of this paper.

hand, binding instruments can be made flexible through allowance of explicit ex-post adjustment mechanisms in the agreement or through the use of vague language, which is later interpreted by the countries themselves or in a central forum. The degree of precision in language is the second choice faced in crafting an agreement. As with non-binding instruments, vague language gives greater flexibility and more easily accommodates heterogeneous circumstances. It also allows for easier adjustment than treaties as uncertainties are resolved. However, vague language also makes compliance monitoring more difficult and detracts from the credibility of the commitment.

Implementing the agreement requires certain functions, such as information sharing, monitoring, dispute resolution, and enforcement. Lessons learned from the literature on optimal devolution and principals of subsidiarity clearly stress the need to devolve responsibility to the lowest level possible. One can then use federated structures to improve monitoring and compliance. In terms of the four functions above, the issue is how best to harness "lower level" knowledge and capacity to implement and monitor agreements while simultaneously recognizing that greater centralization of certain functions provides greater credibility and overall compliance. For instance, centralized monitoring and/or dispute resolution mechanisms can address otherwise potential weaknesses arising from the use of non-binding agreements or of vague language. It is worth noting that these functions can be performed at more than one level in a federated structure. Finally, enforcement is almost never centralized. Rather, agreements are either enforced through national mechanisms or through reputation effects, the latter of which can often be very effective.

As discussed above, international cooperation in the management of ocean fisheries is necessary because of the nature of the resource's externalities and high difficulty in monitoring. The UN Convention on the Law of the Sea (UNCLOS) is a legally binding international treaty, covering a variety of ocean uses through very specific language, including exclusive economic zones, navigation rights and obligations, and pollution prevention. In the area of living resources of the oceans, the convention is more vague and is left open to interpretation and enforcement by signatory nations. However, the strength of the convention lies in its establishment of strong international structures that include information platforms, monitoring mechanisms, and dispute resolution mechanisms, though their relation to fisheries was not well defined. The convention has been greatly effective in areas where its language is more precise but has had very limited effectiveness in managing the ocean's living resources. Bringing more clarity and specificity to ocean fisheries, the UN FAO implemented the FAO Code of Conduct on Responsible Fisheries, a non-binding instrument with weak structures but more precise language. Though non-binding, this Code is able to utilize existing UNCLOS structures for monitoring and compliance. Combined with the development of Regional Fisheries Management Organizations under UNCLOS (following the principles of federated structures), there appear to have been some gains made vis-à-vis past performance, though certain stocks are still highly depleted. Further efforts to promote the sustainable management of living resources in the oceans are being made with the establishment of the Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing, a legally binding instrument with precise language specifying obligations for both flag and non-flag states. This agreement also has weak structures, utilizing instead existing UNCLOS structures, but there is great hope for its future success through specific requirements and enforcement.

Forest management is an area where global agreement has been elusive, primarily because the global externalities of forest management are difficult to define. Demonstrative of the difficult progress in this area is the UN Non-Legally Binding Instrument on All Types of Forests, an obviously non-binding agreement with vague language. This agreement has all of the signs of an ineffective agreement: non-binding nature; vague language; and no information sharing, joint monitoring, or dispute resolution structures. Assessing compliance with this agreement is nearly impossible, and its effectiveness in furthering sustainable management in the future is doubtful. A good contrast with the UN Forest Agreement is the Central African Forests Commission (COMIFAC), a regional body among 10 Central African nations created by a legally binding treaty. The establishing treaty is binding but explicitly makes the sustainable use of forests a voluntary commitment of members. Its fuzzy standards are left open for later refinement, but the structures created in COMIFAC include activity information, coordination platforms, and federated monitoring. The later COMIFAC Plan of Convergence represents a step toward narrowing the specific areas for future regional harmonization. The effectiveness of COMIFAC and its Plan are still difficult to assess, but they appear to have the proper elements to be a successful resource agreement. Through a combination of non-binding standards and a strong structure, COMIFAC is aiming to integrate and coordinate the regions forest management.

Finally, McCarthy noted that there are other international mechanisms that affect natural resources, including voluntary private sector adoption of guidelines or participation in "payments for environmental services" markets, market-based certification/labeling, and within other development financing mechanisms (e.g., the CADDP process), of which environmental sustainability is one of four pillars that need to be addressed to secure financing.

McCarthy concluded that, for the most part, natural resources with supra-national externalities are already generally covered by existing international agreements. However, there is scope to improve the efficacy of these agreements. First, a better understanding of how the design elements either complement or substitute for one another could be used to strengthen agreements. Second, these agreements could also better incorporate lessons learned from the principles of subsidiarity/federated structures literature in order to strengthen compliance. Preserving the natural resource base is critical for achieving and maintaining food security, and that this is even more important in the face of climate change. Improving design of governance instruments is key to preserving the natural resource base and ensuring food security.

GLOBAL PUBLIC GOODS: FOOD SAFETY[33]

Laurian Unnevehr, Economic Research Service, U.S. Department of Agriculture[34]

Laurian Unnevehr discussed the international consensus on food safety issues, identifying four main conclusions. First, food safety is an important public health challenge in developing countries. WHO (2002) estimates that 2.2 million people die each year from food and waterborne disease in developing countries. However, there is substantial uncertainty surrounding such estimates, and the WHO is undertaking a more systematic assessment of the global burden of foodborne illness. Animal and human health management are linked through zoonoses such as highly pathogenic avian influenza (HPAI). Microbial pathogens are the most

[33] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Laurian Unnevehr (May 3, 2011).
[34] The views expressed in this presentation are those of the speaker and are not intended to represent the views of USDA.

important risk, but mycotoxin exposure is also important in developing countries. The science of identifying, monitoring, and tracking foodborne risks is advancing, making better control more feasible. Climate change may alter risks or make risks more dynamic through changing the environmental conditions that foster pathogens or toxins or by increasing the incidence of weather-related emergencies.

Secondly, Unnevehr noted that food safety is a global public good because risks are shared across borders and mechanisms of control require international coordination. Microbial pathogens can enter the supply chain at many points between farm and consumer, and mixing commodities from multiple sources increases the potential spread of risks. Growing trade in perishable products, changing consumption patterns, and increased preparation of food away from home all lead to greater need for coordinated management of food safety along the entire global supply chain. Externalities from hazard control and asymmetric information lead to incomplete market incentives for food safety improvement.

Thirdly, there is an emerging international consensus regarding the best practices for food safety management and regulation. International institutions are emerging to support food safety in both public and private sectors. There is also an emerging international consensus that a preventative, risk analysis based approach to food safety, which addresses the entire supply chain from farm to table, is the best way to design management and regulation. Developed-country regulations increasingly follow this approach, which prioritizes risks according to their public health importance, addresses critical control points with preventive measures, and mandates traceability for identifying risk sources. Private sector certification schemes are increasing, and there are efforts to coordinate and benchmark different systems. The Sanitary and Phytosanitary (SPS) Agreement under the WTO provides a framework for addressing the need for global "standards for standards."

Finally, increased investment in capacity and in institutions would strengthen the ability of the global food system to respond to emerging food safety challenges. Investments in surveillance, water and sanitation infrastructure, and "standards for standards" would enhance management capacity. Institutions are incomplete for carrying out the tasks of prioritizing risks on a global basis, sharing the benefits of control between winners and losers, and providing consistent information about the food safety performance.

GENERAL DISCUSSION

Emmy Simmons opened the discussion by posing a question to Nancy McCarthy related to solutions for encouraging collective action and voluntary compliance. Simmons inquired if these might not be limited solely to joint monitoring but would extend to joint science efforts as well, specifically inquiring about how often she identified global collaboration on science as part of her review of the global treaty process. McCarthy responded that in her review, she found that river basin organizations, as well as efforts by the United States and Canada to monitor certain fish stocks on the rivers, generated scientific data. She did not note a strong emphasis related to this issue in any of the forestry treaties that she reviewed. There is also great variability in the treaties and the way they are managed and enforced. Participants discussed challenges of the Rhine River Basin and Indus Basin treaties. McCarthy noted that regarding river basin treaties, she found that when these areas faced prior conflicts, the new treaties tended to be stronger and more effective.

Participants also discussed food safety perceptions related to GMOs, noting that despite evidence that these types of crops can increase productivity and reduce environmental damage, public perception in many places of the world is that GMOs are unsafe and unhealthy. One participant observed that obviously there is an international disagreement about GM food and GM food safety and it is not clear that there is an institution that is currently capable of resolving this issue.

Per Pinstrup-Andersen reiterated Laurian Unnevehr's point that international institutions for food safety should be strengthened, but inquired as to how specifically she would recommend this be done. Unnevehr stated that with regards to increasing CODEX[35] enforcement capability, she believes that it is impossible to develop international standards for food safety, particularly as risk management activities are individual-country specific and cannot be predetermined. Rather, Unnevehr stated that when she discussed strengthening international institutions, she was in fact referring to giving these organizations more authority to take a broader assessment of prioritizing risks rather than focusing on standards for a specific crop or use of pesticide. She added that the World Health Organization's efforts to assess the global burden of foodborne illness are a positive step but could also be strengthened.

Simmons summarized the presentations noting several crosscutting themes identified throughout the day related to achieving food security, including the need for additional research, better use of science, improved documentation efforts, and the need for location-specific data in some cases. She added that although the goal is the same, to achieve global food security, the presentations had demonstrated that the approaches for meeting this challenge vary extensively.

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[35] The CODEX Alimentarius is a food code used by global consumers, food producers and processors, national food control agencies and the international food trade. It is designed to protect the health of consumer and ensure fair trade practices encouraging the coordinating of international food standards.

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POLITICAL, ECONOMIC, AND INSTITUTIONAL OPPORTUNITIES AND BARRIERS

The last segment of the workshop focused on what changes (in public policy and regulatory institutions, markets and other economic institutions dominated by the private sector, and social and cultural institutions) would be needed to raise the probabilities for ensuring that food availabilities in 2050 respond to global food demands and the nutritional needs of more than 9 billion people. The session began with discussions on environmental externalities and the costs of natural resource degradation; political economy issues, priorities and political will; and incentives and limitations to action by civil society and private sector. The last panel session considered ways to confront trade-offs, remove national and international externalities, seek multiple wins, and establish coalitions as well as partnerships to ensure sustainable food security for all.

EXTERNALITIES: THE COSTS OF NATURAL RESOURCE DEGRADATION[36]

Jason Clay, World Wildlife Fund

Jason Clay began his presentation by stating that environmental externalities are those impacts to the environment that are not included in a product's price—the impacts are external to pricing. They are, in effect, subsidies. In this case, however, they are not subsidies from government but rather subsidies from nature. And, in value, the subsidies from nature probably represent as much as ten times all the subsidies from governments combined.

Two considerations are important when thinking about environmental externalities. First, on a finite planet with increasing population and consumption, we will be hard pressed to pass off the costs of production and consumption to the planet. WWF's Living Planet Report (2010) suggests that we are already living at 1.5 planets—that is, that we are living beyond the ability of the planet to replenish renewable resources, much less the nonrenewable ones. As we add more people who consume on average even more than today, environmental externalities will pose more significant threats to our ability to produce food, amongst other things. The particularly worrisome issue is that technology gains (e.g., in the case of food genetics, equipment, BMPs, etc.) are not able to keep pace with, and help mitigate, the current drawdown on our natural resource base.

The second consideration is whether sustainability should be considered a luxury or a necessity. In today's markets, the question is how much more will consumers pay for sustainable products than for unsustainable ones. Perhaps, given that we are currently consuming resources on a finite planet faster than they can regenerate, unsustainable products should perhaps cost more than sustainable ones.

[36] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Jason Clay (May 4, 2011).

From our experience dealing with subsidies in agriculture, we know that when producers are subsidized, there is less incentive to be more efficient, and innovation comes only when farmers are forced to survive and even thrive without external support. On a finite planet, the cost of externalities will need to be factored into prices. Given shortages of arable land, water, phosphate and potassium, we will probably see markets begin to address these issues. The question is whether it will be fast enough to avert a food security crisis. Put another way, the question is whether consumers should pay the real costs of production? As arable land, soil fertility, and health and water scarcity are all increasing issues globally, we need to figure out how the relative cost of food can possibly continue to decline. In the United States, we pay the least, at just over 10 percent of household income.

Agriculture is currently the largest threat to the planet of any human activity. It is the leading cause of habitat conversion and deforestation. The key crops on the agriculture frontier are beef, soy and palm oil. Agriculture uses twice as much water as all other human uses combined, and currently it takes about 1 liter of water to produce one calorie of food globally. Some 12–15 major rivers run dry at least part of the year. Agriculture is the largest source of pollution and not just in developing countries where agriculture is the primary economic activity but also in the United States and UK. Agriculture uses more chemicals than any other human activity. And, finally, as a result of agricultural practices over the past 150 years, we have lost an estimated 50 percent of remaining top soil around the world.

Although the impacts of large-scale, commercial agriculture and small-scale less intensive or more subsistence oriented agriculture are different, it is not clear which forms of agriculture have the most impacts. It depends on the issues being compared and the methodologies being used. What is clear moving forward, however, is that regardless of the technologies in use or the scales of production, whatever per capita impacts are acceptable with 7 billion people will not be with 10 billion.

To put it another way, the issue going forward with regard to producing more with less is how to think, not what to think. We need to focus more on the desired results and less on the means to achieve them. Adopting a BMP (better management practice) approach will achieve compliance, but it won't stimulate innovation. If we want innovation, we should identify the results we want and let producers and others find different ways to achieve them. This will stimulate the development of a range of new BMPs, some of which will produce results that far exceed those we think are now possible.

As the old adage goes, you manage what you measure. So what should we measure? Taking into account the fact that producing anything has impacts, the issue moving forward will be to define which are acceptable and which are not. We also need to shift our thinking from maximizing any one variable to optimizing several of them. For example, total productivity is perhaps less important than production per key inputs (e.g., water, soil, N, P, K, pesticides, etc.). In terms of protein, we might measure grams of protein consumed as feed versus grams of protein coming out as food.

Most environmental impacts of producing food are not included in the prices paid to farmers and then passed on to buyers. Water is a good case in point. The following table shows the amount of water it takes to grow raw materials used as ingredients to manufacture four common products. The amount the farmer was paid was insufficient to pay a decent price for water, much less all the other expenses farmers have in producing any of the crops.

Table 4-1 Externalities, Products and Prices--The Case of Water

	Raw Material Input	Water to Produce Input	Farm Gate Price
1 cotton T-shirt	4 oz. ginned	500-2,000 liters	US$0.20 (Australia)
1 Liter of soda	6 T. sugar	175-250 liters	US$0.006 (Brazil)
1 oz. slice of cheese	6 oz. milk	40 liters	US$0.03 (USA)
1 double-quarter pounder	8 oz. hamburger	3,000-15,000 liters	US$0.26 (USA)

SOURCE: Clay, J. W. 2009. The Political Economy of Water and Agriculture. pp. 29-37 in *Water and Agriculture: Implications for Development and Growth.* Washington, DC: Center for Strategic and International Studies.

We cannot measure every environmental externality. We need to focus on those that are the most critical. It would also be strategic to focus on those that already have markets. We should use markets to incorporate those values into pricing. For example, we have carbon markets, so ideally we could develop markets to pay farmers for their carbon along with other products they produce. This carbon could include what is sequestered as well as what is avoided. The unit would be in CO_2e (carbon dioxide equivalent) emissions. As water becomes more scarce, water markets are beginning to develop. And as farmers are confronted with higher prices for water, they use it more efficiently.

Farmers, too, are beginning to find that addressing environmental externalities can make them more productive and more profitable. For example, farmers who maintain or improve soil quality have to buy fewer soil amendments. Farmers in Brazil and Indonesia have found that buying degraded land and rehabilitating it for soy and oil palm is more profitable than is clearing forests or other natural habitat. In fact, in Brazilian farmers make more money growing soil than growing soy, when one takes into account the increased value of land from increasing soil carbon (Landers, 2007). In fact, for every 0.5 percent soil carbon they introduce into the soil, they reduce their input use, on average, by about 10 percent. In another case, Central American coffee producers have found that they can increase coffee production by up to 30 percent if they maintain sufficient habitat to accommodate pollinators. We live on a finite planet. We have limited resources, but both population and per capita consumption are increasing. We need to protect the planet's resources for future generations. There is no such thing as a free lunch. Addressing environmental externalities will increase the price of food. However, eroding our resource base will also increase the cost of producing food.

As the Oromo of Ethiopia say, "You can't wake a person who's pretending to sleep." We need to wake up to the fact that we live on a finite planet.

POLITICAL ECONOMY ISSUES, PRIORITIES AND POLITICAL WILL[37]

Robert Paarlberg, Wellesley College

How can we persuade government officials to take the actions needed to increase global food security? If there were an easy answer to this question, it would have been done already.

[37] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Robert Paarlberg (May 4, 2011).

Robert Paarlberg focused his discussion on the policy actions in greatest need of change: the public investment policies of national governments in Africa. He focused on Africa because this is the only region where food security is certain to worsen in the years ahead under a business as usual scenario. He also focused on public investment policies because policies in other areas--including exchange rate policies, fiscal policies, market policies, tariff policies, and regulatory policies--have improved significantly in Africa since the 1980s. Only public investment policies are lagging behind.

Africa’s rural investment deficits become conspicuous to anyone travelling in the countryside. African governments must spend more on rural roads, rural power, agricultural R&D, agricultural extension, and small-scale agricultural irrigation. Weak public support for these investments has been holding back the productivity of the smallholder sector in Africa, perpetuating the poverty and hence the food insecurity of this large segment (on average 60 percent) of the population. Roughly 70 percent of all farmers in Africa live more than a 30 minute walk from the nearest all weather road, so most household transport still consists of carrying things on foot (Calvo, 1998). These high transport costs make inputs like fertilizer too expensive at the farm gate, and they reduce incentives to grow a surplus for the market. Also, only 4 percent of farmland in Africa is irrigated, and almost nobody has access to electrical power, powered machinery, veterinary services, or public extension agents. These deficits all persist because governments in Africa continue to devote only about 5 percent of their public budgets (on average) to agricultural development. The Government of India, in the early years of the Green Revolution, devoted more than 20 percent of its public budget to agricultural development. African leaders pledged in 2003 to increase their investment level to 10 percent, but only a handful delivered on that pledge.

How can governments in Africa be persuaded to meet their own promise and double their current investments in agricultural development? We can’t count on farmers in Africa to demand this change in policy, because farmers in Africa have a weak political voice. Most are women, not literate, not politically organized, not armed, and physically remote from each other and from the capital city. We also cannot count on intergovernmental organizations--such as the special agencies of the United Nations (like FAO)--to perform this task. FAO resolutions, passed at “food summits” in Rome, are non-binding and unfunded. We also cannot count on international NGOs to persuade African governments to redirect their spending. These NGOs have little influence over African spending decisions; the rural services delivered by NGOs can even give governments an excuse to do less, rather than more.

In the end, the job of encouraging national governments in Africa to make larger public investments in the farming sector falls heavily on the bilateral and multilateral donor community. Here, of course, a second problem arises. It is not just African governments that have under-invested in agriculture over the past three decades; it is the donor community as well. Between 1980 and 2006, United States official development assistance to agriculture in Africa declined by 86 percent. This, at a time when food grain production was falling on a per capita basis in Africa, with numbers of chronically malnourished people doubling. Between 1978 and 2006, the share of World Bank lending that went for agricultural development also declined, from 30 percent down to just 8 percent. So instead of persuading African governments to spend more on agriculture, the donor community spent most of the past three decades signaling that less spending would be appropriate.

Have the international food price spikes of the past three years persuaded donors and African governments to correct their under-investment tendencies at last? In response to the

2008 price spike, the donors did pledge to do better. At a meeting in Italy in 2009, the G8 countries pledged to increase their agricultural assistance to at least $20 billion over the coming three years, despite the financial crisis they were experiencing at the time. But then, even as international food prices were again trending upward in 2010, this aid revival effort faltered. Austerity policies reduced the willingness of donors in Europe to increase their assistance to agriculture, and Congressional appropriators dragged their feet in the United States as well. The Obama administration tried hard to meet its G8 pledge level of $1.2 billion a year for agriculture, even requesting $1.8 billion in FY11 for what it was now calling a "Feed the Future" initiative. But in the end, Congress appropriated only $913 million, and the FY12 appropriation will be more difficult, with the House of Representatives now under control of Tea -Party influenced Republicans. Other ominous signs included a 19 percent Congressional cut in appropriations for the Millennium Challenge Corporation (MCC), which funds rural infrastructure projects in Africa, plus defeat of the Lugar-Casey 2009 Global Food Security Act, a bipartisan measure that would have authorized a larger USAID effort in agricultural infrastructure, education, and R&D in Africa. This worthy measure passed the Senate Foreign Relations Committee unanimously in 2009 but was blocked by a single senator, on budget grounds, and never came to a vote on the Senate floor.

So, there are actually two categories of policy officials now failing to pass the "political will" test: governments in Africa and decision makers in the donor community. Paarlberg stated that this should not be framed as a money problem, because the alternative to investing more today in African agriculture will not be cheap. It will be an endless demand in Africa for expensive food aid.

INCENTIVES AND LIMITATIONS TO ACTION BY CIVIL SOCIETY[38]

Brian Greenberg, InterAction

Brian Greenberg began his presentation with an overview of the civil society sector and the work of non-governmental organizations (NGOs) as it relates to agricultural development and food security. He noted that generalizations about "civil society" or the "NGO sector" should be made cautiously. These broad terms encompass a wide range of organizations that play diverse roles in international agricultural development and food security. International NGOs, local civil society groups, community service organizations, cooperatives, and associations of many types are grouped under this broad label. Operational models range from charitable, mission-driven approaches to not-for-profit businesses and encompass both faith-based and secular organizations. Civil society activities span policy analysis, programs, research and advocacy, and reflect a wide range of political, social and economic objectives.

With an ability to mobilize about $6–9 billion annually for development and humanitarian assistance, the civil society sector rightly considers itself a significant donor. NGO investments in agricultural development remained relatively stable in recent decades, as major donors greatly reduced their levels of official assistance. InterAction's Food Security Aid Map (http://foodsecurity.ngoaidmap.org) displays nearly 800 currently active NGO programs in food security, a number representing a fraction of the global total. As observers have noted,

[38] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Brian Greenberg (May 4, 2011).

coordination and alignment of these investments has sometimes been a challenge for this community.

The agricultural development and food security programs of NGOs reflect a spectrum of motives and missions. The Millennium Development Goals (MDGs), human rights and a belief in the importance of civil society's "third way"--a critical counterbalance to the dominant power of the private sector and governments--are unifying principles within this community. Characteristic strengths and capabilities of NGOs include sustained community engagement, the use of predominantly local staff, and a reliance on partnerships with other civil society organizations, governments and the private sector. Productivity gains and market participation that serve the interests of smallholders are important to the NGO agricultural development community. A commitment to building the capacity of local counterparts is increasingly a feature of international NGO (INGO) programs.

The realization that many indicators of food security have been moving in the wrong direction in recent years has made an appreciation of the importance of food security programs close to universal among NGOs. With nearly 1 billion people now chronically undernourished, and with demand for additional production often contributing further to environmental degradation, an attitude of humility about the record of development in addressing these problems is widespread in the NGO community.

Aid effectiveness principles rooted in the Paris and Accra declarations are proving important touchstones for the NGO community. Yet though "country ownership" has been advanced by governments as centrally important, and though they have pledged to create more enabling environments for civil society roles in development, actual measures to mobilize and partner with civil society to achieve development objectives have been limited. Community engagement and mutual accountability are areas of current NGO advocacy to make aid effectiveness principles more a reality than a promise. To achieve the spirit of the Paris and Accra declarations, the NGO Open Forum has created a set of accountability and transparency principles for the sector with the goal of inducing greater alignment and collaboration with governments. Another critical touchstone for the NGO community has been an appreciation of the centrality of women to development outcomes. Gender-relational approaches to engaging and empowering women, in which the attitudes and behaviors of men are understood as a root cause of gender disparities, are increasingly influential.

Human capital, technical capacity, organizational development, and effective partnerships are remaining challenges for the NGO community. Realizing that the magnitude of development challenges requires an "all hands on deck" mobilization, ways to partner more broadly and effectively are among the most urgent needs. Another important response to the scale of rural poverty and hunger has been efforts to achieve closer alignment and greater consistency in the approaches and objectives of civil society organizations, the private sector and governments. The leverage or synergy that will be needed among all development organizations to achieve the MDGs is proving a powerful inducement to expanded consultations and coordination.

Another set of challenges is rooted in difficulties in addressing the root causes of poverty and hunger. Many programs tackle one or a few dimensions of what are typically very complex and interwoven problems. Lingering sectoral and disciplinary loyalties pose challenges in tailoring program responses to the multi-causal sources of real world problems. Food price rises, for example, are a product of complex contributing factors rooted in imperfect markets, rising energy costs, tariff and trade rules, biofuel demand and commodity speculation. Most agricultural development programs do not address or lack the mandate to tackle this sort of complex challenge. Another persistent and critical constraint has been weak public and political understanding of foreign assistance and its links to diplomatic and security concerns. This lack of understanding has in part been responsible for the fall in support for agricultural development in recent decades.

In an environment of greatly reduced resources for development assistance, it remains to be seen whether the trend of underinvestment in agriculture can be reversed by recently escalating food prices and the rising number of hungry people. An emphasis in policy making and government circles on short-term outcomes--despite the reality that rural development is a long term process--poses a persistent challenge for programs in the field. Widespread market failures in providing key inputs, information and labor resources, and in offering small scale producers reasonable rewards for their output, continue to be all too typical of rural areas in many countries. The persistent marginalization of women, and the restriction of rights, mobility, safety and security of assets that they need to become effective economic agents, is perhaps the greatest brake to rural development.

At the strategic or existential level, the greatest threat to sustained rural development is a lack of appreciation for the critical importance of environmental health and stability in agricultural production. The nature and magnitude of environmental constraints is not widely understood or appreciated. Beliefs that destructive production systems can be compensated for with ever-greater inputs of fertilizer, water and pesticides continue as mainstream in many agricultural development circles. Strategies and techniques for securing greater production from smallholders in the face of escalating environmental degradation and scarcity are urgently needed.

From the standpoint of mission-drive civil society organizations trying to improve the lives of the world's poorest and most vulnerable populations, a more supportive and enabling policy, legal and regulatory environment for their operations is among the highest priorities. Too often, governments perceive NGOs as political threats because of the work they do, the credibility they gain and the loyalty they secure within the communities where they work. Too often, governments choose not to engage or choose to carefully marginalize civil society in setting development strategy, building capacity on all sides, implementing programs and monitoring the benefits delivered to those most in need.

NGOs will continue to work towards programs that appropriately integrate across sectors, such as environment and gender, that have frequently been stove-piped. This will entail less precedence and unchallenged priority for the disciplines that have traditionally dominated agricultural development: economics and agronomy. As the cross-cutting and complex nature of development challenges becomes better appreciated, approaches and insights from the social sciences, ecology, gender, community engagement and local governance, etc., will need to be more actively solicited and integrated into lasting development solutions.

INCENTIVES AND LIMITATIONS TO ACTION BY THE PRIVATE SECTOR[39]

Dennis Treacy, Smithfield Foods

[39] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Dennis Treacy (May 4, 2011).

Modern, large-scale animal agriculture is a crucial component of the sustainability challenge. Smithfield Foods Inc.'s (Smithfield's) experience in producing safe, nutritious and affordable food in a responsible manner illustrates how key business priorities can stimulate sustainable practices and environmental benefits.

Government and society have the potential to create both barriers and incentives to sustainability. Misinformation in the current public discourse on food and agriculture is often based on ideology, not sound science or fact. This influences public opinion and policy and remains a threat to true sustainability. It is imperative that thought leaders such as the National Academies--the nation's preeminent source of high-quality, objective advice on science, engineering, and health matters--balance the dialogue and shape sound policies, inform public opinion, and advance the pursuit of sustainable food production.

Dennis Treacy provided an overview of Smithfield's experience in sustainable intensification, with examples of existing barriers and limitations to sustainable food production, as well as opportunities that may enhance sustainable practices.

Smithfield's Programs

Over the years, Smithfield grew from a regional meat company to a global food supplier with operations currently in twelve countries and sales to nearly forty. Today, Smithfield Foods is the world's largest producer and processor of pork, offering consumers more than 50 brands of pork products as well as more than 200 gourmet foods.

During the past twenty years of rapid growth, Smithfield has been building comprehensive sustainability programs step by step. The company began by focusing principally on environmental compliance in order to address enforcement issues arising during the 1990s (Smithfield Corporate Social Responsibility ("CSR") Report, 2009/2010). It revamped internal departments, creating new positions to oversee a new environmental approach and apply consistent practices, policies, and procedures across the company. It developed an internal environmental compliance review program to determine where gaps were occurring and how to fix them (Smithfield CSR, 2009/10). The company implemented a structured, systematic approach through a comprehensive environmental management system (EMS) based on the International Organization for Standardization (ISO) 14001 program.[40]

Smithfield's were the first hog farms in the United States to go through the ISO process. Before long, the company became the world's first livestock production company to receive EMS certification under the rigorous standards established by ISO. Once the EMS program was established for Smithfield's hog operations, the company adopted it for domestic and international processing facilities. Today, 578 farms and facilities, or more than 95 percent of Smithfield's operations worldwide, are ISO 14001 certified (Smithfield CSR, 2009/2010).

These efforts have resulted not only in great strides in environmental performance, but also in making more food using fewer natural resources. For example, while the company has grown into a global company, the company has also achieved over the past five years a 60 percent water efficiency improvement at first processing facilities (which produce whole cuts of meat) on a normalized basis, a 22 percent reduction in electricity use at company farms, and a 4 percent absolute reduction in our direct and indirect greenhouse gas (GHG) emissions. Last year, we estimated that these improvements and environmental improvements have reduced company

[40] See Environmental Management System/ISO 14001. http://water.epa.gov/polwaste/wastewater/Environmental-Management-System-ISO-14001-Frequently-Asked-Questions.cfm. Accessed on September 29, 2011.

costs by $100 million over that time period (Smithfield CSR, 2009/2010). This estimate will likely increase substantially in 2011.

While these changes first arose from the desire to achieve better compliance, these efforts have continued, accelerated, and expanded in response to business priorities--our focus on high margin/high volume products and improved capacity utilization, responding to customer preferences, achieving cost reductions through more efficient operations, and improving employee health and safety. Moreover, what began with an environmental focus has expanded to each of the company's five key sustainable performance areas: environment, animal welfare, food safety and quality, communities and employees. The company has utilized its EMS model and approach to each of these core areas and has experienced similar progress under each (Smithfield CSR, 2009/2010).

Smithfield has continued to work on embedding sustainability concepts in its company culture, emphasizing leadership, performance and accountability. In 2002, the company produced its first Corporate Social Responsibility Report, detailing early improvements in the environmental arena and, through stakeholder input, now uses the Global Reporting Initiative (GRI) metrics as the basis for documenting the environmental, social and economic impacts of its operations.[41]

Market Demand for Protein

The United Nations projects that world population will reach at least 9 billion people by 2050 and has called for an increase in world food production by 100 percent within the same timeframe. Global demand for and consumption of animal protein, particularly in rapidly developing countries such as Brazil and China, will continue to increase, although the levels there are still below the levels of consumption in most other industrialized countries. The UN Food and Agriculture Organization (FAO) suggests that global meat production and consumption will rise from 233 million tonnes (2000) to 300 million tonnes (2020).

This demand is caused in part by the growth in the human population but also because of urbanization and the increasing affluence of the emerging economies and the growth of the middle class. The high-value protein that the livestock sector offers improved nutrition for these new consumers and also provides an important source of a wide range of nutrients. For many people in the world, particularly in developing countries, livestock products remain a desired food for nutritional value and taste. If this demand is to be met, providers of animal protein, including meat, dairy and fish, must focus on more intensive farming and yield, improvements in natural resource management, and advances in technology.

Barriers and Limitations

Unbalanced reporting and outright misinformation in popular writing about modern, large scale agriculture can encourage barriers and limitations to sustainable intensification. A casual web search easily reveals numerous articles with negative headlines but little in terms of actual research or factual support.

In contrast, a recent study published in the February 2011 edition of *Foodborne Pathogens and Disease* details a remarkable success story about how modern swine production has largely eradicated common pathogens endemic to swine, but it has garnered very little

[41] See Global Reporting Initiative. http://www.globalreporting.org/Home. Accessed on October 3, 2011.

attention on the web or in the press (Davies, 2011). There, Dr. Peter Davies, of the University of Minnesota, published an exhaustive study focusing on claims oft-repeated in today's press that modern intensive hog farms has increased the risk of major foodborne pathogens common to the to the pig species. His study determined just the opposite--that large-scale, modern production has virtually eliminated those pathogens. In fact, Davies found that pigs raised in old, outdoor systems "inherently confront higher risks of exposure to foodborne parasites." Modern, intensive swine production "represents a substantial health achievement," Dr. Davies writes, "that has gone largely unheralded." Indeed, Dr. Davies observes that "[m]isinformation in public discourse has achieved pandemic potential with the rise of blogging and other social networking tools" and "are mostly ideological and heavily value laden." Unfortunately, such misinformation can misdirect the efforts of policymakers and color the views of government officials.

Food productivity gains from intensive production are also threatened by poorly conceived government policy. For example, in the United States, ethanol policies have driven nearly 40 percent of the annual corn crop into ethanol production for fuel, directly and substantially driving up feed costs for livestock and jeopardizing the economic viability of meat producers (USDA, 2011). The federal Volumetric Ethanol Excise Tax Credit has been in place in one form or another for more than three decades and now provides billions in support to a mature industry (U.S. Congressional Budget Office, 2010). As consumption grows with the federal Renewable Fuels Standard, so does the cost of the tax credit. Corn-based ethanol is the only product that is supported three ways by the government: with a 45 cent per gallon tax subsidy, a 54 cent per gallon tariff on imported ethanol, and a mandate that forces the public to buy the fuel. Although many in the food industry support development of alternative energy sources, it should reject a flawed corn-based ethanol policy that results in higher food prices for the consumer and limited net benefit on greenhouse gas (GHG) emissions (U.S. Congressional Budget Office, 2009).

Another example is a rulemaking being considered presently by the U.S. Department of Agriculture's Grain Inspection, Packers and Stockyards Administration (GIPSA). In 2010, GIPSA issued a proposed rule regarding the marketing of livestock and poultry. Of particular concern are provisions that would cause use of marketing agreements between producers and packers to be severely reduced or to disappear, and provisions that would prohibit packers who own livestock from selling those animals to another packer--all of which actually aim to discourage more efficient, intensive animal agriculture.

Incentives and Opportunities

On the other hand, government incentives aimed at reducing key impacts of food production have the potential to encourage sustainable practices. Such incentives, if utilized on a broad scale, would also encourage sustainability in animal agriculture. An example of a successful incentive structure is found in the state of North Carolina. There, the state passed a renewable portfolio standard (REPS) in 2007 requiring electricity providers to obtain a minimum percentage of their power from renewable energy resources. Under this new law, investor-owned utilities in North Carolina are required to meet up to 12.5 percent of their energy needs through renewable energy resources or energy efficiency measures. A portion of their energy needs must also come from swine and poultry wastes. These electric power suppliers generally may comply with the REPS requirement in a number of ways, including the generation of power at new renewable energy facilities. North Carolina's incentives have driven development of renewable energy projects at Smithfield's farms and should be considered in regions where large-scale, modern farms operate.

Another important incentive is the reduction of trade barriers. Currently, most food is consumed in the country in which it is produced (Clay, 2010). Increasing trade will foster an increase in global food supply (USDA, 2008). It will also allow the marketplace to reward the most efficient companies and those actively engaged in more sustainable, intensive agriculture with more opportunities to reach markets in areas that may not have such sustainable solutions. In 2011, Congress was considering free trade agreements with South Korea, Panama, and Columbia. These agreements would offer U.S. companies, including Smithfield, vastly expanded access to consumers in these countries. As an example, one of the largest economies in the world, South Korea, provides a great opportunity for food industries to expand exports of sustainable products and to allow consumers to choose from an abundance of safe, nutritious and affordable food options.

Conclusion

Although no single strategy will solve the global food problem or fully address the challenge of feeding nine billion people, Smithfield's experience in sustainable intensification helps inform the discussion. Modern, large-scale animal agriculture can help meet the sustainability challenge and often does so based on fundamental business priorities. Treacy stated that NAS can help balance the debate through science-based examination and by providing a hard look at the sacred assumptions in so much popular writing about modern production practices.

PANEL: CONFRONT TRADE-OFFS, REMOVE NATIONAL AND INTERNATIONAL EXTERNALITIES, SEEK MULTIPLE WINS, AND ESTABLISH COALITIONS AND PARTNERSHIPS

Emmy Simmons, U.S. Agency for International Development (ret.)Melinda Kimble, United Nations Foundation
Carol Kramer-LeBlanc, U.S. Department of Agriculture

Emmy Simmons led off the panel by providing highlights from the previous days' discussion. She noted that Mike Bushell made the point that sustainable agriculture/sustainable food security is a journey, not a destination. The external environment, science and public perceptions are constantly evolving. Phil Pardey reminded participants that while technology in many sectors is evolving rapidly, dealing with biological process--with complex social and economic process--will take a long time, and the outcome we want in 2040 will rely on action that the world community is taking today. Robert Paarlberg noted that past underinvestment in agriculture, combined with the new demographic bubble, made new investments increasingly important.

Simmons explained the hard constraints to increasing global food supplies--how water, sun, temperature and land match up against potential interventions. The limited availability of land, the intensification of land use, and the institutional weaknesses undermine the incentives to use land more sustainably. Property rights are one of the key issues that are delaying more intensification of land use as well as more investment in the land and productivity increases. The question of scale, with regard to the intensification of land use, is one of the big issues. Simmons also noted constraints with regard to existing biodiversity highlighting Tim Benton's point that the management of existing biodiversity resources, especially those linked to forests and oceans, often seemed to be widely separated from agriculture. Simmons mentioned that another hard constraint is water use. There has to be more efficiency of water use, but there may be some absolute limits to increasing the efficiency of water use, as explained by David Molden. Simmons questioned how those absolute limits can be dealt with in terms of food supplies, particularly as related to local increases in production and productivity.

Simmons noted that there was a hard constraint in the form of inadequate stocks of knowledge in producers' heads and along the value chain. Initial stocks of knowledge among producers and along the value chain need to be rapidly built up. Brian Greenberg explained that NGOs often work at the community level and work with marginal producers in an effort to increase knowledge stocks, which will generate the rate of productivity growth needed for sustainable intensification. There was also a hard constraint with regard to fertilizer availability because of limited supplies of potassium and phosphorus. Donald Crain estimated there will be 300 years of potassium supply with no substitute--it will take a long time for innovation.

Simmons emphasized the need to take deliberate, coordinated, purposeful steps in terms of defining an agenda, noting that developing metrics for both planning and monitoring are critical areas for investment. Simmons highlighted the following three areas for additional investment to support expanding sustainable food supplies:

1. Spatially based datasets to permit management and manipulation of information at different scales, such as the plot scale, farm scale, landscape scale, water basin scale, and global scale.
2. Longitudinal information that permits assessment of dynamics, rather than snapshots or cross-sectional information.
3. Better information about what the appropriate level of investment in data should be (e.g., who should do it, how it can be longitudinal, how it can be spatially aware, and how this information base can best be integrated for a more sustainable food secure future). Underinvestment in data, which was discussed at the first workshop, has been confirmed by the second workshop.

Melinda Kimble's presentation[42] focused on the institutions required to manage the global commons and to meet the challenges of achieving global food security. She highlighted the work of the UN High Level Task Force on Food Security, which was modeled on the World Economic Forum's (WEF) recommendations to redesign UN and other intergovernmental institutions to better address 21st century challenges. Although prescient, the WEF Global Redesign Initiative has received minimal attention. Yet, the GRI is one of the more comprehensive reports to date, as it highlights the need for more of the G-8's traditional economic leadership role to move to more representative groups of governments, most logically, the G-20. The report also urges involvement of civil society, the private sector, and private philanthropy. This presentation highlighted how the World Bank and the UN applied these concepts to improve delivery of both food aid and policy support through the reform of the Committee on Food Security--a pilot attempt to put into practice increased multi-stakeholder

[42] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Melinda Kimble (May 4, 2011).

engagement and promotion of developing country and private sector participation in designing better solutions to complex global problems. Who sits at the table is important, but there are two other imperatives for success:

- High level (head of government) commitment to action is required.
- New informatics that provide a better understanding of problems and that establish baselines and performance metrics in order to measure success.

The new Committee on Global Food Security includes a broad coalition of agencies:

- FAO, World Food Program, International Fund for Agriculture Development (IFAD) (all Rome-based)
- World Health Organization (WHO), International Labor Organization (ILO), UN Trade and Development secretariat (UNCTAD), Office of the UN High Commissioner for Refugees (UNHCR), Office of the High Commissioner for Human Rights (all Geneva-based), and World Trade Organization (WTO)
- World Bank and International Monetary Fund (IMF) (Washington-based) and Organization for Economic Cooperation and Development (OECD) (Paris-based)
- UN funds and programs--UNDP, UNICEF, UNEP, and the Secretariat players--UN Department of Economic and Social Affairs, UN Department of Political Affairs, UN Peacekeeping, and UN Department of Public Information.

The group also solicited the input of grain traders, private philanthropies and other agricultural experts. This new governance effort also incorporated the UN reforms embedded in recommendations of the 2006 Coherence Panel--to improve interagency coordination and delivery at the field level--and we see the beginnings of the institutional response to the 2008 crisis and the establishment of the High Level Task Force on Food Security to track the issues, define problems and recommend action.

As the global financial crisis unfolded, the international community continued to move on reforming and strengthening the management of global food security. By April 2010, the effort was well underway, with the World Bank and France playing leading roles. The Advisory Group for the new Committee, which held its first meeting in 2010, included new philanthropic players (e.g., the Bill & Melinda Gates Foundation) and private sector trade groups. Twelve countries make up the Committee on World Food Security. As discussions proceeded, a new singular voice emerged, and a unified Secretariat supported by the Rome agencies worked to expand the analysis and dialogue on a range of solutions. This approach aims at engaging relevant UN agencies to focus on individual elements of the planning process, integrating their various activities toward a single set of national objectives that are designed to achieve the Millennium Development Goals most relevant to food security. The "change management framework" is being field tested in eight countries, several of which have severe food security challenges.

The ultimate goal of "one UN" is to consolidate offices, work program planning and resources into a single country package addressing national food security. This new approach to technical assistance at the country level should be directly reinforcing of the global planning and coordination process under the new Committee on World Food Security. These complementary processes hold the potential to provide the countries and the international community a better window on what works globally and at country level. They also provide opportunities for flexible and adaptive management and information sharing, as well as performance benchmarking.

The first opportunity to evaluate these reforms is the WCFS meeting in Rome in October 2011. This meeting will provide an opportunity to assess initial results and examine the ongoing challenges facing agriculture, food and nutrition. A five-year work plan for the WCFS will be introduced at this session, along with a new assessment of global food security. Collectively, all this work holds promise for testing some of the GRI principles--high level commitments, multi-stakeholder participation, coordinated planning and new informatics--as the UN works on refining and consolidating its ability to deliver capacity-building interventions on the ground. Should this effort prove effective, it could well prove an adaptive model for better coordination around global challenges.

Carol Kramer-LeBlanc focused her discussion on health, sustainable agriculture and evolving food systems. She talked about the growing importance of obesity concerns in USDA policy circles but noted that nutritional improvements in school lunch programs are constrained by budget cost. She expressed her concern that food insecurity in the United States and globally has been more severe since the 2008 food price crisis, particularly for women and children. She talked about the major U.S. initiative known as Feed the Future. USDA, the Department of State and USAID are leading this effort. One particular element of the program that had been emphasized by Hillary Clinton in speeches at the United Nations is its focus on nutritional interventions for children, particularly in the first 1,000 days of life. Other USDA international efforts include work with the Commission on Sustainable Development that looks at the issues on agriculture, rural development, land, drought and desertification associated with agriculture has been inserted in the task force on poverty. She noted, however, that most USDA resources are spent on U.S. domestic issues. Kramer-LeBlanc reiterated Robert Paarlberg's point that a major challenge is to convince politicians of the value of international development activities.

GENERAL DISCUSSION

Following the panel discussions, a number of observations and questions were shared. Hartwig de Haen led off by recommending that the new institutions and initiatives mentioned by Melinda Kimble should be evaluated. He further suggested that, from a global perspective, systems of food security governance should be measured against the following three criteria:

1. Does the system have mechanisms in place that would prevent future crisis, or at least cushion the vulnerable, poor and hungry against the effects of such a crisis?
2. Does the system assure that all the governments abide by their commitments that they have repeatedly expressed at global summits?
3. Do the global mechanisms, including the reformed intergovernmental Committee on World Food Security (CFS), provide adequate dynamic leadership globally toward a lasting eradication of hunger in the longer term, a respect for the right to food, and elimination of malnutrition including overnourishment?

Hartwig de Haen emphasized that a massive global campaign on the implications of non-action is needed. Marco Ferroni said that one of the main messages coming from the workshop was the importance of productivity enhancements as a means to assuring sustainable food security. He said that productivity and sustainability go hand in hand and questioned whether the global management institutions discussed by Jason Clay and Melinda Kimble were adequately focused on the productivity paradigm. Kimble suggested that global conversations have been underway for the last twenty years, and they will impact our ability to take directed action for or against agricultural intensification and productivity.

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A

WORKSHOP AGENDA

A Sustainability Challenge: Food Security for All

Workshop 2: Exploring Sustainable Solutions for Increasing Global Food Supplies

Date: May 2-4, 2011
Location: Venable LLP Conference Center, Capitol Room
575 Seventh Street NW Washington, DC 20004

BRIEF BACKGROUND AND OBJECTIVE:
Individual and household food security depends on access to the food needed to meet food and nutritional needs, a condition strongly related to household income. Food availability is necessary, but not sufficient, to achieve food security. However, availability of sufficient food for current and future generations is critical and must be based on sustainable methods of production and distribution that is, using resources available now in such a way that their availability for production and distribution in the future is not compromised or precluded. Recent and current debate surrounding recent food price volatility and the impact of climate change on the future food supplies make the topic very timely and important.

While keeping in mind the critical importance of access to food, this workshop focuses on the question of sustainable food availability and the related natural resource constraints and policies. The overall objective is to identify (i) the major barriers to expanding food production to meet future food demand without damaging the future productive capacity and (ii) policy, technology and governance interventions that could reduce these barriers and promote sustainable food availability as a basic pillar of sustainable food security.

WORKSHOP STRUCTURE:
This workshop will build on the findings of a first workshop, in which expert participants explored the availability and quality of metrics that help us understand the concept of “sustainable food security.” On the theory that “you can’t manage what you can’t measure,” consideration was given to the metrics of: poverty; undernutrition or “hunger”; malnutrition; farm productivity; natural resource productivity (land, water, soil quality, etc.); and food supply chain efficiencies or losses. It was clear that there were different ways of understanding and measuring these concepts and relating them to each other (e.g., household poverty and children’s’ heights) in meaningful ways. The use of different geographic scales was particularly striking as relevant data on production and productivity, for example, related variously to: households, fields, farm, landscapes, river basins, nations, regions, or continents. By being “spatially explicit,” it was believed that data and information relevant at smaller scales could also be meaningfully aggregated to meso- and macro-scales.

Overall, however, experts in Workshop 1 concluded that:

- The quality of metrics is not as good as it needs to be for accurately understanding, monitoring, or predicting food security and the sustainability of food production processes given natural resource conditions, policies, and market incentives;

- Suites of metrics/indicators are needed to understand the phenomena associated with sustainable food security (both availability of food and access of poor populations to it), although even existing suites of metrics are rarely integrated adequately for decision makers today; and
- There are few integrated sets of relevant data that are widely accessible and allow analysts to work at sufficiently broad scales as well as at more local (including household) scales.

The first day of this second workshop will open with a recap of findings from Workshop 1, reflecting the availability and quality of data indicators and projections of both poverty/food security and resource use trends as they are currently understood, while also framing the potential of various factors to pose new opportunities, risks and vulnerabilities that will affect trends going forward. These presentations will enable workshop 2 participants to see what the existing evidence tells us regarding the magnitude of the problems and challenges and opportunities for their solutions.

Subsequent sessions on day one of Workshop 2 will then dig more deeply into the trends associated with natural resources that are believed to pose hard constraints to food supply and availability. The second day of this second workshop will then explore several of the policy, market, and governance approaches currently thought to be needed to resolve the constraints posed by natural resources to food availability at various scales: global, regional, and local. The third day will engage participants in consideration of what changes (in public policy and regulatory institutions, markets and other economic institutions dominated by the private sector, and social and cultural institutions) would be needed to raise the probabilities for ensuring that food availabilities in 2050 respond to global food demands and the nutritional needs of more than 9 billion people.

NOTES:
Presenters will be asked to prepare written papers to support their oral presentations. This workshop will involve a diverse set of participants: researchers, analysts, academics, and development leaders in a wide range of fields – food production, resource management, environmental conservation, climate, and others.

Monday, May 2, 2011

8:30 AM **Welcome and a Conceptual Framework for the Workshop**
Per Pinstrup-Andersen, Cornell University, Committee Chair
This presentation will be based on a conceptual model developed to show the links between sustainable food production/supply, food security and interventions by the public and private sector and civil society. The model will provide the framework for the content and organization of the workshop.

HOW SERIOUS IS THE CHALLENGE TO ACHIEVE SUSTAINABLE FOOD SECURITY?

9:00 AM **Current and Expected Future Food and Nutrition Security**
Hartwig de Haen, Former FAO Assistant Director-General, Economic and Social Department
This presentation will set the stage for what needs to be accomplished. It will present scenarios for the future trends in food security based on the best evidence available and it will assess the quality of the evidence drawing on outcomes of the first workshop and other relevant projections. The nature of the dietary transition, the triple burden of malnutrition and other relevant issues should be included to provide the foundation for subsequent presentations.

9:30 AM **Future Agricultural Productivity and Changes in the Endowment of Natural Resources**
Philip Pardey, University of Minnesota
A brief description of the trends and challenges on the basis of the best evidence available and it will assess the quality of the evidence drawing on the outcomes and other relevant projections.

10:00 AM **Are New Agricultural Paradigms Needed to Facilitate Sustainable Food Security in the Context of Uncertainties and Risks**
Marco Ferroni, The Syngenta Foundation for Sustainable Agriculture
Climate Change, Technology Choices, Biofuels, Energy Prices, and Shifting Markets for Resources

10:30 AM Q&A and Discussion with the Audience

11:00 AM BREAK

11:20 AM **The Natural Resource Constraints to Sustainable Increases in Food Production**
Moderator: Jason Clay, World Wildlife Fund
These presentations should assess the constraints, the challenges and the opportunities for removing the constraints to achieve sustainability. Each presentation should make global and regional assessments and identify the regions where the constraints are most critical and where the challenges are the greatest. The importance of the food system in the demand for the particular resource and competing demands should be considered. Since a subsequent section will deal with possible interventions, these presentations should focus on an assessment of the problems and challenges but may also include suggestions for resource-specific interventions by the public and private sector and civil society. Findings from workshop 1 may be included as appropriate.

- **Water** David Molden, IWMI
- **Land and Forests** Paul Vlek, University of Bonn
- **Marine Fisheries and Aquaculture** Jason Clay, World Wildlife Fund

12:20 PM LUNCH

1:20 PM

- **Biodiversity and the Future Food Supplies** Tim Benton, Leeds University
- **Soil Quality of Tropical Africa: An Essential Element of Improved Agricultural Productivity** Uzo Mokwunye, Development Strategy Consultant

2:50 PM Q&A and Discussion with the Audience

3:20 PM BREAK

3:40 PM **Dealing with Climate Change**
Moderator: Bert Drake, Smithsonian Environmental Research Center (ret.)

- **Climate Change Projection and Potential Impact on the Food System** Jerry Nelson, IFPRI
- **Risks and Vulnerabilities** David Lobell, Stanford University

4:40 PM Q&A and Discussion with Audience

5:00 PM END of DAY ONE

6:00 PM **Working Dinner for Steering Committee and Invited Guests**
Restaurant Nora Garden Room, 2132 Florida Avenue NW, Washington, DC
- Presentation of Data Quality Monitoring: Prabhu Pingali, The Bill & Melinda Gates Foundation
- Discussion

Tuesday, May 3, 2011

APPROACHES TO ACHIEVING SUSTAINABLE FOOD AVAILABILITY AT AFFORDABLE PRICES: THE ROAD TO SUSTAINABLE FOOD SECURITY FOR ALL FOR THE FORESEEABLE FUTURE

Several potential approaches to achieving sustainable food availability will be discussed. Most of these already have champions and many have undergone some pilot testing, providing some information on strengths and weaknesses. Presenters will take this learning and experience into account and provide subjective assessments as to scalability and broad impact, impact on affordability of food, and relative contributions to sustainability.

8:30 AM **Conclusion of Dinner Discussion and Recommendation for Follow-up**
Prabhu Pingali, The Bill & Melinda Gates Foundation

9:00 AM **Farm-level Sustainability Intensification**
Mike Bushell, Syngenta
Farm level sustainable intensification through farm-focused management improvements, supported by S&T.

9:30 AM **Food Value Chains Leading to Sustainable Intensification**
Maximo Torero, IFPRI
Enable smallholder farmers to link into markets through commodity value chains, institutional innovations, incentives and credit to achieve sustainable intensification.

10:00 AM **Ecosystem Management**
Jeffrey Milder, EcoAgriculture Partners
Taking an ecosystem conservation approach focused on conserving stored carbon in plants, encouraging more carbon sequestration and assuring sustainable management of natural resources while expanding food production, through agricultural and environmental regulation and best practices for sustainably intensified production. The role of organic production.

10:30 AM BREAK

10:50 AM **Reduction of Yield Gaps to Increase Productivity Sustainability**
Jude Capper, Washington State University
Address the yield gap; increase productivity of crops and animals for consumption by applying science and technology while achieving sustainable and more efficient use of natural resources. Are transgenics an option? Where do organic approaches come in?

11:20 AM **Energy Efficiency**
Amit Roy, IFDC (Presented by Donald Crane, IFDC)
Since a key metric of food production is energy produced, a focus on increased energy efficiency of production systems (less energy inputs per unit of energy produced, using less fossil fuel, deploying alternative sources of energy for production) will contribute to a more sustainable food system.

11:50 PM Discussion of Morning's Presentations: Do they add up, offer complementary alternatives?

12:30 PM LUNCH

1:30 PM **Private Investment and Farm Size Issues**
Derek Byerlee, CGIAR
Are there economies of scale in primary production? Are land tenure systems capable of supporting any needed changes in farm sizes without destabilizing inequities? What is the role of recent and on-going land acquisitions in low-income Africa? Will that lead to sustainable food production increases?

2:00 PM **Losses and Waste in the Supply Chain**
Adel Kader, University of California, Davis (Presented by James Gorny, U.S Food and Drug Administration)
How large are the losses and wastes and how can they be reduced through better management (agribusiness role), new technologies (S&T role) or some other way?

2:30 PM Q&A and Discussion with the Audience

3:00 PM BREAK

3:20 PM **Global Public Goods: Natural Resources**
Nancy McCarthy, FAO
Managing natural resources for sustainable food availability and food security must go beyond national boundaries. River basin organizations, organizations like the Congo Basin Initiative, provide some regional governance. Is a greater degree of global coordination needed? How might it be organized?

3:50 PM **Global Public Goods: Food Safety**
Laurian Unnevehr, Economic Research Service, U.S. Department of Agriculture
Food safety is managed by both private sector market players and national governments. Food safety challenges may increase with globalization and climate change. Are there new approaches to managing food safety sustainably in global supply chains?

4:20 PM Discussion, Wrap Up and Summary

5:00 PM END of DAY TWO

Wednesday, May 4, 2011

TAKING ACTION: POLITICAL, ECONOMIC AND INSTITUTIONAL OPPORTUNITIES AND BARRIERS TO CHANGE

8:30 AM **Endogenize the Social Costs of Natural Resource Degradation and Climate Change**
Jason Clay, World Wildlife Fund
Introducing the concepts of full costing, PP, PES, multiple wins and application to natural resource management and climate change to strengthen the resource base and achieve a sustainable future food supply.

9:00 AM **Political Economy Issues, Priorities and Political Will**
Rob Paarlberg, Wellesley College
Consider both national and international issues including national and international agricultural and trade policies.

9:30 AM **Incentives and Limitations to Action by Civil Society**
Brian Greenberg, InterAction

10:00 AM **Incentives and Limitations to Action by the Private Sector**
Dennis Treacy, Smithfield Foods

10:30 AM BREAK

10:50 AM **Panel: Confront Trade-Offs, Remove National and International Externalities, Seek Multiple Wins, and Establish Coalitions and Partnerships**
Moderator: Laurian Unnevehr, U.S. Department of Agriculture
- Panelist 1: Carol Kramer-LeBlanc, U.S. Department of Agriculture
- Panelist 2: Emmy Simmons, U.S. Agency for International Development (ret.)
- Panelist 3: Melinda Kimble, United Nations Foundation

11:35 AM Q&A and Discussion with Audience

12:15 AM **Concluding Comments**
Per Pinstrup-Andersen, Cornell University, Committee Chair

12:30 PM ADJOURN for Public Session

B

WORKSHOP PARTICIPANTS

Per Pinstrup-Andersen (Chair)
Cornell University

Jeffrey Albanese
U.S. Department of Agriculture

Pat Basu
U.S. Department of Agriculture

Tim Benton
Leeds University

Richard Bissell
National Academy of Sciences

Mike Bushell
Syngenta

Derek Byerlee
CGIAR

Jude Capper
Washington State University

John Campbell
InterAcademy Council

Jason Clay
World Wildlife Fund

Donald Crane
International Fertilizer Development Center

Giselle Cubillos
U.S. Department of Agriculture

Hartwig de Haen
University of Göttingen

Bert Drake
Smithsonian Environmental Research Center (ret.)

Karen Edwards
World Soy Foundation

Marco Ferroni
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Helen Keller International

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Development Strategy Consultant

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Agricultural Assessments International Corporation

C

BIOGRAPHICAL INFORMATION: PLANNING COMMITTEE, SPEAKERS AND STAFF

PER PINSTRUP-ANDERSEN (Committee Chair and STS Roundtable Member) is the H.E. Babcock Professor of Food, Nutrition and Public Policy, the J. Thomas Clark Professor of Entrepreneurship, and Professor of Applied Economics at Cornell University and Professor of Agricultural Economics at Copenhagen University. He is past Chairman of the Science Council of the Consultative Group on International Agricultural Research (CGIAR) and Past President of the American Agricultural Economics Association (AAEA). He has a B.S. from the Danish Agricultural University, a M.S. and Ph.D. from Oklahoma State University and honorary doctoral degrees from universities in the United States, United Kingdom, Netherlands, Switzerland and India. He is a fellow of the American Association for the Advancement of Science (AAAS) and the American Agricultural Economics Association. He served 10 years as the International Food Policy Research Institute's Director General and seven years as department head; seven years as an economist at the International Center for Tropical Agriculture, Colombia; and six years as a distinguished professor at Wageningen University. He is the 2001 World Food Prize Laureate and the recipient of several awards for his teaching, research and communication of research results. His research and teaching include economic analyses of food and nutrition policy, globalization and poverty, agricultural development, the interaction between the food system and human health and nutrition, and agricultural research and technology policy.

TIM BENTON is Research Dean in the Faculty of Biological Sciences at the University of Leeds, and Professor of Population Ecology. He has previously been on the staff at the Universities of Stirling and Aberdeen (UEA), undertook postdoctoral work at UEA and has a PhD from Cambridge and undergraduate degree from Oxford. His research interests are broad and concern managing populations under environmental change; with much of the specific work concerning the theory of population dynamics and the practice of managing biodiversity in agricultural settings. The population dynamical work includes development of theory informed by empirical understanding derived from a laboratory model organism, a soil mite. Within the role of research dean, he has been exposed to a wide range of biomedical and molecular sciences and has developed a strong interest in "systems approaches". He has worked on many different questions: from identifying the appropriate scale of management, to patterns of biodiversity in the fossil record, but all have at their core understanding how the environment affects behavior and life history, and how the responses are summed across individuals to produce population dynamics.

MIKE BUSHELL (Committee Member) is head of Jealott's Hill International Research Centre in the United Kingdom. Dr. Bushell has recently taken up a new role in global R&D as principal scientific adviser and is also secretary to Syngenta's Science and Technology Advisory Board. Dr. Bushell graduated with a B.Sc. in organic chemistry from Liverpool and a Ph.D.

from Liverpool/University of California at Davis. Dr. Bushell came to Jealott's Hill in 1980 as a team leader in insecticide research, following postdoctoral work in Cambridge. Since 1990, Dr. Bushell has held various management positions in chemistry and bioscience and has also worked within Zeneca Specialties in Manchester. He returned to Jealott's Hill in 1999 as sector leader for insect and fungal control. Within Syngenta he has previously been head of R&T projects, head of discovery, head of strategy and technology, and head of external partnerships.

DEREK BYERLEE is the chair of the Standing Panel on Impact Assessment of the Consultative Group for International Agricultural Research (CGIAR) and a consultant and adviser to a number of international organizations. Formerly he was rural strategy adviser for the World Bank and co-director of the 2008 World Development Report: Agriculture for Development. Before joining the Bank, he was director of economics at the International Maize and Wheat Improvement Center (CIMMYT) and associate professor at Michigan State University. For most of his career he worked in several postings in Africa, Latin America and Asia conducting field research on agricultural technological change and food policy. He has published widely in several fields of agricultural development.

JUDE CAPPER is an Assistant Professor of Dairy Sciences in the Department of Animal Sciences at Washington State University. She undertook her undergraduate and graduate degrees at Harper Adams University College (UK) where her post-graduate research focused on the relationship between ruminant nutrition and neonatal behavior. Following a two-year lectureship in Animal Biology at the University of Worcester (UK), her post-doctoral research at Cornell focused on two areas: ruminant lipid metabolism, and modeling the environmental impact of dairy production. At Cornell, Jude worked with Prof. Dale Bauman to develop a deterministic model of the environmental impact of dairy production, based on the NRC (2001) nutrient requirements for dairy cows. At WSU, her program focuses on quantifying the environmental impact of dairy and beef production systems, identifying the factors that contribute to mitigating resource use and greenhouse gas emissions and communicating the results to producers, consumer and policy-makers. Current projects include comparisons of the historical and modern US beef industry; evaluation of the effect of dairy breed on the environmental impact of cheese production; and quantifying the impact of performance-enhancing technologies on resource use and greenhouse gas emissions from beef production.

JASON CLAY (Committee Member) is Senior Vice-President of Market Transformation in the World Wildlife Fund (WWF). Over the course of his career Jason Clay has worked on a family farm, taught at Harvard and Yale, worked in the U.S. Department of Agriculture, and spent more than twenty-five years working with human rights and environmental organizations. In 1988, Clay invented Rainforest Marketing, one of the first fair-trade ecolabels in the United States, and helped create Rainforest Crunch. From 1999-2003, Clay co-directed a consortium with WWF, World Bank, UN Food and Agriculture Organization, and National Aquaculture Centres of Asia/Pacific to identify better management practices for shrimp. He has convened multi-stakeholder roundtables to reduce the impacts of producing salmon, soy, sugarcane, cotton and palm oil. Clay leads WWF's efforts to work with private sector companies to improve their supply chain management, particularly ingredient sourcing and carbon and water neutrality. Clay is the author of 15 books (most recently, World Aquaculture and the Environment (in press), Exploring the Links between International Business and Poverty Reduction: A Case Study of

Unilever in Indonesia (2005) and World Agriculture and the Environment (2004) and more than 250 articles and 500 invited presentations. Clay studied at Harvard and the London School of Economics before receiving his Ph.D. at Cornell University in 1979 in anthropology and international agriculture.

DONALD CRANE is Senior Development Officer and Washington Area Representative for the International Fertilizer Development Center (IFDC). He provides liaison with USAID and other donor agencies and partners and helps develop and manage IFDC agribusiness projects in Africa, Eastern Europe, and Asia. Mr. Crane has over 30 years of experience promoting economic growth and organizational management for development assistance. Prior to joining IFDC, Mr. Crane from 1979 to 2004 was a key leader in the growth of ACDI/VOCA where he assisted the president in perfecting the merger of Agricultural Cooperative Development International and Volunteers in Overseas Cooperative Assistance to form ACDI/VOCA. From 1997 to 2004, he served as Executive Vice President/Senior Advisor to the President and as president of ACDI/VOCA supporting organizations: Agricultural Services International, Planning Assistance, and VOCA Foundation. Mr. Crane also served as Project Officer for Africa, Near East, Asia, and the Pacific. He has served as Chairman of the Board of the Overseas Cooperative Development Council (OCDC); as Secretary of the Board of Volunteers in Economic Growth Alliance (VEGA); and, as Member of the Board of the Society for International Development (SID). Mr. Crane has an M.S. in food and resource economics, University of Florida, Gainesville, Florida, and a B.S., accounting, University of Maryland, College Park, Maryland.

HARTWIG DE HAEN is retired Professor, Department of Agricultural Economics and Rural Development, University of Göttingen. From 1990 to 2005 he was Assistant Director-General of the Food and Agriculture Organization of the United Nations (FAO) in Rome. From 1990 to 1994 he was head of FAO's Agriculture Department and from 1995 until his retirement head of the Economic and Social Department. He has studied at the Universities of Kiel and Göttingen and at Michigan State University/USA. He holds a Ph.D. in Agricultural Economics. During his time in academic institutions he was a member of research and policy advisory bodies, including the Council of Scientific Advisors to the Federal Ministry of Economic Cooperation and Development (Chair from 1988-1990). He has published books and articles in the fields of production economics, development economics, agricultural policy and environmental economics.

BERT DRAKE (Committee Member) is a former plant physiologist at the Smithsonian Environmental Research Center in Edgewater, Maryland and the leader of two major ecosystem projects on the impacts of rising atmospheric CO2 and climate change. The Chesapeake Bay wetland study is now in the 23rd year making it the longest running experiment of its type ever undertaken. In collaboration with NASA, the CO2 study was expanded in 1996 to include similar studies of a nutrient and water limited dwarf oak forest on Merritt Island Wildlife Refuge at the Kennedy Space Center, Florida. These studies have resulted in more than 100 publications and involved collaborators, post doctoral fellows and graduate students from many foreign countries and the US. A popular lecturer, he has been invited to speak on the impact of global warming on terrestrial ecosystems to a wide range of educational and professional organizations. In 2005, he was designated the Distinguished Research Lecturer by the Smithsonian Institution for his long record of research and public outreach.

MARCO FERRONI (**STS Roundtable Member)** is the Executive Director of the Syngenta Foundation for Sustainable Agriculture. Before joining the Foundation, Dr. Ferroni, an expert in international agriculture and sustainability issues, worked at the Inter-American Development Bank (IDB) and the World Bank in Washington, DC. As a Deputy Manager of the Sustainable Development Department of the IDB, he had responsibility for regional sector policy and technical support to the Bank's country departments. As the Principal Officer in the Bank's Office of Evaluation and Oversight, he directed evaluation studies that assessed the relevance, performance and results of Bank strategies and investments. As a senior advisor at the World Bank he advised on donor relations and directed work on international public goods and their role in foreign aid and international affairs. Earlier in his career, he was an economist and division chief in the government of Switzerland, working in development cooperation. Marco Ferroni holds a doctoral degree in agricultural economics from Cornell University.

JAMES GORNEY currently serves as a Senior Advisor for Produce Safety at the U.S. Food and Drug Administration's Center for Food Safety and Applied Nutrition in the Office of Food Safety. Dr. Gorny's primary responsibility is to advise the Director of the Office Food Safety on policies and programs affecting the safety of fresh produce. Prior to joining the U.S. Food and Drug Administration, Dr. Gorny served as the executive director of the Postharvest Technology Research and Information Center at the University of California, Davis. From 2000 to 2007 Dr. Gorny served as Senior Vice President of Food Safety & Technology for the United Fresh Produce Association / International Fresh-cut Produce Association which merged in 2006. Dr. Gorny received his Ph.D. in plant biology from the University of California at Davis in 1995, and his B.S. and M.S. degrees in food science from Louisiana State University in Baton Rouge. He is the author and editor of numerous scientific and technical publications pertaining to the quality and safety of fresh produce. He is also the 2005 recipient of the International Fresh-cut Produce Association Technical Award. Actively involved in the fresh produce industry since 1986, Dr. Gorny has worked extensively on perishables quality and food safety issues including development and implementation of Good Agricultural Practices, modified atmosphere packaging design, quality assurance, operations, and general management issues, both nationally and internationally.

BRIAN GREENBERG is the Director of Sustainable Development at InterAction, an alliance of US NGOs engaged in international development and humanitarian assistance. His experience in rural development extends from sustainable agriculture and natural resource management to capacity building for NGOs and communities. The interface between climate change and agriculture has been an area of increasing focus for Dr. Greenberg over the past 10 years. His field experience includes work in Egypt, India, Jamaica, Nepal, Ethiopia and the Democratic Republic of Congo. Dr. Greenberg has experience in field survey methods, participatory rural appraisal, agricultural development, monitoring and evaluation, conflict assessment and mitigation, gender issues, natural resource management, strategic planning and organizational capacity assessment and strengthening. Dr. Greenberg has a B.S. in Biochemistry from Dickinson College, a M.A. in Cultural Anthropology from Brown University, and a Ph.D. in Anthropology from the University of Chicago. His prior professional experience includes academic research and teaching, a Science Policy Fellowship at the American Association for the Advancement of Science, and independent consulting.

ADEL KADER is a Professor of Postharvest Physiology in the Department of Plant Sciences at the University of California at Davis. His research deals with postharvest biology and technology in relation to preserving flavor and nutritional quality of intact and fresh-cut fruits. He has published more than 200 technical publications and edited and co-authored a book on Postharvest Technology. Dr. Kader received awards for outstanding teaching in 1989 and for distinguished graduate mentoring in 2003 from UC Davis. He was elected a Fellow in 1986 and President in 1996 of the American Society for Horticultural Science. Dr. Kader received the Award of Distinction in 2000 from the College of Agricultural and Environmental Sciences at UC Davis. In April, 2010 he received an honorary doctorate degree from the University of Cartagena in Spain.

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ROUNDTABLE ON SCIENCE AND TECHNOLOGY FOR SUSTAINABILITY

Established in 2002, the National Academies' Roundtable on Science and Technology for Sustainability provides a forum for sharing views, information, and analyses related to harnessing science and technology for sustainability. Members of the Roundtable include senior decision-makers from government, industry, academia, and non-profit organizations who deal with issues of sustainable development, and who are in a position to mobilize new strategies for sustainability.

The goal of the Roundtable is to mobilize, encourage, and use scientific knowledge and technology to help achieve sustainability goals and to support the implementation of sustainability practices. Three overarching principles guide the Roundtable's work in support of this goal. First, the Roundtable focuses on strategic needs and opportunities for science and technology to contribute to the transition toward sustainability. Second, the Roundtable focuses on issues for which progress requires cooperation among multiple sectors, including academia, government (at all levels), business, nongovernmental organizations, and international institutions. Third, the Roundtable focuses on activities where scientific knowledge and technology can help to advance practices that contribute directly to sustainability goals, in addition to identifying priorities for research and development (R&D) inspired by sustainability challenges.

In September 2009, the Roundtable adopted a two-pronged strategy to address sustainability. The first part of this strategy attempts to define inter-sectoral dynamics essential to long-term science and technology approaches to sustainability. The second looks to apply these approaches and concepts to sustainability challenges.

- *Focus on Long-Term Science and Technology Strategy for Sustainability*
  Acknowledging that sustainability is an interdisciplinary topic that crosses domains, sectors, and institutions, the Roundtable launched a series of discussions to outline the major connections between human and environmental systems. This focus builds on the comparative advantage of the Roundtable versus the field-specific boards around the National Research Council. Past discussions topics included energy linkages (September 2009), water linkages (May 2010), land linkages (October 2010) and linkages of non-renewable materials (May 2011).

- *Applied Sustainability*
  As a second area of programmatic emphasis, the Roundtable is sharpening its focus on sustainability challenges in applied situations where STS works with specific communities within our RT membership.

The Roundtable is the key component of the Science and Technology for Sustainability (STS) Program in the division of Policy and Global Affairs at the National Research Council. The Roundtable is being supported by the National Academies' George and Cynthia Mitchell Endowment for Sustainability. STS is the institutional focal point within the National Academies for examining sustainability science and technology issues. Sustainability leaders in the government, academia, private sector and non-governmental organizations recognize STS as a sustainability leader driving current approaches in the field.

For more information, please visit our website at: www.nas.edu/sustainability or contact Marina Moses, Director of the National Academies' Roundtable on Science and Technology for Sustainability (mmoses@nas.edu; 202-334-2143).

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