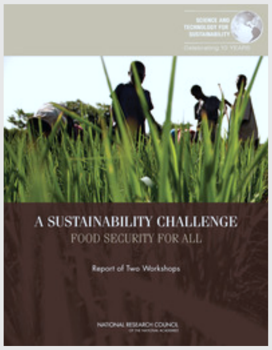

A Sustainability Challenge: Food Security for All: Report of Two Workshops (2012)

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A Sustainability Challenge: Food Security for All

Report of Two Workshops

Committee on Food Security for All as a Sustainability Challenge

Science and Technology for Sustainability Program

Policy and Global Affairs

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This report and the workshops 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

To follow up on discussions held by the National Research Council's Roundtable on Science and Technology for Sustainability, an ad hoc committee of experts was appointed to organize two workshops to address the sustainability challenges associated with providing food security for all. The first workshop, *Measuring Food Insecurity and Assessing the Sustainability of Global Food Systems*, examined the empirical basis for past trends, the current situation, and projections for the future. The second workshop, *Exploring Sustainable Solutions for Increasing Global Food Supplies*, explored a set of issues fundamental to assuring that food supplies can be increased to meet the needs of the world's growing population—now expected to reach over 9 billion by 2050.

The issues addressed during the workshops were timely, as food security and agricultural development have become priority topics for the international leaders meeting regularly at the Group of Twenty (G-20) as well as critical elements in the United Nations climate change negotiations launched in Copenhagen in 2009. In February 2011, the committee hosted the first workshop to review commonly used indicators for food security and malnutrition, poverty, and natural resources and agricultural productivity. The overarching objective of the first workshop was to contribute to the global effort towards sustainable food security through the improvement of indicators used to assess and monitor progress. The workshop offered an opportunity for dialogue among a small group of experts, including those responsible for key indicators of food security, key critics of those metrics, end users, and planning committee members. The workshop also sought to analyze methodological strengths and weaknesses and to discuss priorities for improving our understanding of the dimensions (quantitative, qualitative, and geographical) of the issues.

The second workshop, held in May 2011, was designed to identify the major challenges and opportunities for change associated with achieving sustainable food security and identifying needed policy, science, and governance interventions. 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. While sustainable food security for all depends both on food supplies and assuring access to food, the second 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 also discussed 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.

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

[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.

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

The workshops and report could not have come together without the help of many dedicated staff members. Pat Koshel and Emi Kameyama directed the project and coordinated the report. Marina Moses provided oversight. Jennifer Saunders and Dylan Richmond provided invaluable support and assistance with our two workshops 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 was made possible by 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: Chris Barrett, Cornell University; Yurie Tanimichi Hoberg, The World Bank; Daniel Maxwell, Tufts University; Lynnette Neufeld, Micronutrient Initiative; and Sanjay Reddy, The New School for Social Research for Part I of the report; and 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 for Part II of the report.

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. Responsibility for the final content of this report rests entirely with the authors and the institution.

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

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OVERVIEW

There are few areas of human endeavor in which the challenge of sustainability is clearer than in food and agriculture. Farmers and animal keepers must use natural resources—the physical environment of soil, water, and the sun—in ways that generate a continuous supply of food adequate to satisfy people's biological needs for survival and their economic demands. Degradation of soil, inappropriate management of water, and the use of practices that have negative effects on the climate may increase food security in the short run, but will decrease output over time and threaten the survival of future generations. Sustainable management of natural resources and the environment is fundamental to future food security.[1] Action by governments and other agents within and outside the food system may help or hinder sustainability. There is much evidence showing that the current global food system is not sustainable.

In Europe, the United States, and other high-income regions and countries, consumers have become complacent about the ability of the food system to deliver the food they want and need when they want and need it. The use of "improved" technologies, incorporating both scientific knowledge and significant capital investment, has enabled producers to generate substantial volumes of food per unit of natural resource input at affordable prices. New storage technologies have reduced losses and, combined with transport improvements, have limited supply disruptions. Processing technologies have multiplied the number of consumable products derived from a particular crop or animal. Wholesale and retail sales operations have become increasingly efficient in providing the final link to the consumer. Together, production, storage, processing, and delivery operations combine in variable ways and form robust, demand-driven agricultural value chains that deliver safe and tasty food, on a reliable basis, to many consumers. Competition among participants in all segments of the chains helps to ensure that costs are controlled and products are affordable to even low-income consumers in those regions and countries.

By contrast, in many parts of the developing world, much of agriculture is based upon traditional technologies: seed is farmer selected and saved from year to year, most tillage is done by hand labor, and crops are rain dependent (Pretty, 2006). Yields remain low, storage is rudimentary and inadequate to prevent major losses, and processing is still largely home based or artisanal. Large percentages of the population are employed in agriculture, and families tend to consume what they produce, selling some production into markets or working off-farm to generate needed incomes. Urban wholesale and retail food supplies largely depend on the widely dispersed product collection efforts of networks of traders and dealers.

In most of these traditional food systems, quantities produced by farming households are complemented by those produced at a commercial scale by a relatively small number of "modern" farmers and animal operations. Often, these larger-scale operators supply the wholesale markets as well as a small urban-based industrial processing sector. While supermarkets are becoming more important in many developing countries, urban consumers

[1] As defined by the 1996 World Food Summit, "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life." See http://www.fao.org/wfs/index_en.htm. Accessed on June 6, 2011.

purchase much of their food in wet markets or in the surrounding small shops that deal in specific grains and legumes. Foods processed on the street are available for immediate consumption.

It is important to note, however, that neither the modern food systems nor the traditional systems assure long term food security for all. Affordability, physical access, and volatility of both supply and price compromise the ability of poor families and individuals to achieve food security. Furthermore, both modern systems and traditional systems use environmental services in unsustainable ways (Pretty, 2006).

Many of the traditional, family-based systems fail to produce enough food or income to assure that even the producing family has access to a nutritionally adequate diet. Furthermore, surpluses produced by more commercially oriented small-holder farms are not sufficient, in many countries, to assure that all consumers have access to locally sourced, nutritionally adequate supplies at all times at prices they can afford. These countries must, to some extent, rely on imports of food. Low-productivity traditional systems often over-use or mismanage the environmental resources on which future productivity depends: applying insufficient fertilizers to replace nutrients extracted as crops, overgrazing pasturelands held in common, and using groundwater inefficiently.

Modern food systems are more successful in producing reliable supplies of food, but even wealthy, surplus-producing countries do not assure that food is available cheaply enough for all consumers. Supplementary public assistance, such as food stamps, is necessary to cover the affordability gap. Nor are many of the highly developed, industrial food systems sustainable in environmental terms. Damage to the productive capacity of natural resources is rarely integrated into the product pricing structures. Lowering of the groundwater level, pesticide pollution, the effects of poorly managed contaminants, and other environmental impacts generated by the system are rarely included in the price the consumer pays for the food. Rather, these costs are borne by the population at large or result in uncompensated degradation of the natural environment. In effect, failure to include environmental costs into costs of production results in transfers from future to current generations; that is, future generations will face higher costs of production because of the failure to incorporate environmental costs now. On the other hand, incorporating the costs of environmental degradation would increase food prices, and if inappropriately managed, could cause increasing hunger and malnutrition in current generations of low-income people.

The rapid rise in global food prices in 2007-2008 and more recent price volatility have reminded the world of the continued importance of having nutritionally adequate food supplies that are affordable, available in sufficient quantities, and predictably available. It is generally agreed that in the next decades, growing populations and economic expansion will inevitably create supply disruptions and put upward pressure on prices unless agricultural production and productivity are increased; trade mechanisms become much more efficient; and policies are changed to reduce the affect on food crops, for example, those promoting the processing of food crops into biofuels.

It is also generally agreed that the process of climate change will have a negative impact on the production potential of much of the tropics and sub-tropics, the area of the world in which population growth is currently most rapid. While greater productivity in temperate zones could partially compensate for this decline, it is not clear that redistribution from supplying areas to consuming areas could occur at affordable cost, nor is it clear how natural resources would be affected.

In sum, “food security for all” is a significant sustainability challenge. Data on health and nutritional status, especially of children under 5 years of age, indicate that a substantial portion of the world’s seven billion people are not currently nutritionally secure. Data on ecosystem health and use of nonrenewable materials indicate that more natural resource-efficient means for producing the additional volumes of food are needed now to be prepared to feed a global population in excess of nine billion people expected to be reached by 2050 (FAO, 2010b).

In order to better understand how sustainable food security could be achieved, the National Research Council’s Science and Technology for Sustainability Program hosted two workshops addressing the sustainability challenges associated with food security for all. The first workshop was titled *Measuring Food Insecurity and Assessing the Sustainability of Global Food Systems*. A second workshop was titled *Exploring Sustainable Solutions for Increasing Global Food Supplies.* The workshops were held on February 16-17, 2011 and May 2-4, 2011.

Organized by a committee of experts appointed by the National Research Council, the first workshop involved presentations and discussions with a diverse group of experts who explored the availability and quality of commonly used indicators[2] for food security and malnutrition, poverty, and natural resources and agricultural productivity as well as the data sources used. The overarching objective of the first workshop was to contribute to global efforts toward sustainable food security through the improvement of indicators used to assess and monitor progress in improving food and nutritional security and to review projections for increasing agricultural productivity while protecting the long term viability of critical natural resources. The specific objectives were:

- To help establish the dimensions of the sustainable food security challenge;
- To review commonly used indicators from the point of view of the data used (quality, frequency, consistency), construction of the metric or indicator and to analyze methodological strengths and weaknesses;
- To review current uses and misuses of the indicators;
- To identify options for improving existing processes and developing better data and indicators to meet the needs of users; and
- To explore possible peer review mechanisms for improving the metrics[3] and indicators and assuring the proper use for policies and programs.

The first workshop was organized around the three broad dimensions of sustainable food security: (1) availability, (2) access, and (3) utilization. Within these topics, the workshop aimed to review the existing data (i.e., what we know and what we think we know) to encourage action and identify the knowledge gaps. The workshop was organized around the following topics:

- Metrics for food insecurity and malnutrition, including both food consumption indicators and outcome indicators
- Measures of national and global poverty and their use in policy making

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[2] *Indicator* is defined as “a characteristic that indicates a quality or state of a system (something that indicates something useful to someone based on one or more metrics, observations or both*)*.” www.srl.gatech.edu/education/ME4171/IndicatorsMetrics.ppt. Accessed on June 6, 2011.
[3] *Metric* is defined as “a quantitative measure or derivation from two or more measures, which may not necessarily indicate something useful to particular observers (a measure of something that does not necessarily indicate something useful).” See www.srl.gatech.edu/education/ME4171/IndicatorsMetrics.ppt. Accessed on June 6, 2011.

- Measures of agricultural productivity and natural resource use with regard to sustainable food security
- Composite indicators for sustainable production and natural resource use
- Plausible trajectories for sustainably increasing food supplies

Throughout the workshop there were discussions about who uses these measures and for what; what metrics or data various decision makers really need and whether current indicators provide that information; what the priorities are for further research and investments in data collection and data development; whether numbers are comparable between countries and over time; and how good is good enough. Breakout sessions were organized to examine possible ways forward: how the right data and information can be provided within the right institutional and organizational system; how existing and new data collection efforts can be developed to efficiently provide needed information; what additional research is needed to inform processes and to develop more appropriate indicators; and what institutional arrangements are needed.

On the theory that "you can't manage what you can't measure," consideration during the first workshop was given to the metrics of: undernutrition or "hunger," malnutrition, poverty, farm productivity, natural resource productivity (land, water, soil quality, etc.), and food supply chain efficiencies and losses. Participants noted 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. Many workshop participants suggested 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.
- 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.

While recognizing the critical importance of access to food, the second workshop, held in May 2011, focused on the question of sustainable food availability and the related natural resource constraints and policies. 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.

The overall objective of the second workshop 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. 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. Per Pinstrup-Andersen highlighted several themes 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 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 agro-ecological systems in reducing or avoiding continued natural resource degradation. However, adhering to the organic farming practices as defined in the United States and EU 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.

ORGANIZATION OF THE REPORT

This report is divided into two parts. Part I is a summary of workshop one—*Measuring Food Insecurity and Assessing the Sustainability of Global Food Systems*. Part II is a summary of the second workshop—*Exploring Sustainable Solutions for Increasing Global Food Supplies*. Each of these sections includes a selected bibliography, workshop agenda, list of workshop participants, and biographies of speakers. In addition, for workshop one there is a background paper—*What Do We Really Know? Metrics for Food Insecurity and Nutrition* and a brief description of various household surveys cited in the report. The appendixes to the full report include biographies of the planning committee and the roster of members of the Academies Roundtable on Science and Technology for Sustainability.

The report is limited in scope to the presentations, workshop discussions, and background documents distributed to the participants. The report does not necessarily reflect the views of the committee or the workshop participants as a whole.

PART I

MEASURING FOOD INSECURITY AND ASSESSING THE SUSTAINABILITY OF GLOBAL FOOD SYSTEMS

INTRODUCTION

The February 2011 workshop was originally conceived during the 2007-2008 food price crises, when more than one billion people around the world were deemed food insecure. As global food prices rose, many people were unable to purchase enough food to meet dietary needs. Agricultural producers were not able to quickly adjust production patterns or increase overall productivity. Despite substantial price declines in the following year, published data on the number of people who were food insecure fell only slightly, calling into question the data and methodology used to estimate global hunger and its relation to changing global food prices (FAO, 2010b). Furthermore, global food prices are often not indicative of the prices paid locally or their impact on vulnerable populations. That is, the effect of global food price changes on domestic prices depends on commodity and country specific variables, such as the extent to which the country relies on imported foods. It was clear to many participants that a better system of indicators is needed to monitor changes—including rapid changes—so that interventions can be triggered more quickly and efficiently.

Similar concerns were raised about global poverty numbers, as new numbers suggested dramatic increases in the numbers of poor people living in India and China, which seemed inconsistent with the economic expansion occurring in these countries in the last decade.

At the same time, it was not clear whether indicators for natural resources and agricultural productivity were valid and reliable. It was clear, however, that many natural resources were being overused for agricultural production, agricultural markets were not competitive and able to adjust quickly to changes in supply and demand, and significant populations remain unable to produce or buy the food they need.

As the first step in mapping out possible transitions from the current situation to a sustainable food secure future, the workshop planning committee decided to look at the quality and quantity of the data that are available, the evidence that is currently available to support action, and knowledge gaps.

Projections of the number of hungry and food insecure people drive both policy and practice, especially in the planning and delivery of humanitarian assistance or the provision of social safety nets to vulnerable populations. However, the quality and coverage of data on hunger and food security are not as precise as they could be to provide a clear view of the problem or as comprehensive as they need to be to formulate potential global solutions. Recent analysis indicates that past trends of the global number of undernourished people of around 800 million are highly dependent on key assumptions in the methodology used, and that the methodology is less robust than it could be. Furthermore, recent estimates have increased the number of hungry people to more than one billion. Ostensibly linked to the impact of food price fluctuations, these estimates are based on very weak evidence of purchasing power and food choices over very large populations. Poor urban consumers tend to receive more attention than rural consumers, even though it is increasingly recognized that differences in food and nutritional status among rural populations are large. Further, the fact that agencies reporting these estimates receive financial support on the basis of the projected severity of the problem introduces an element of moral hazard into their estimating processes.

Estimates of the availability and consumption of food products are also questionable on other grounds. For example, recent measurements by the International Institute of Tropical Agriculture in Uganda, Rwanda, and Burundi indicated actual yield levels for cooking and brewing bananas at twice the widely published estimates. Long-used methodologies for reporting annual yields are based upon very small samples and assumptions linking rainfall to output. Similarly, assessments of the trends and implications of changes in dietary patterns, particularly in Asia, are not well documented but are increasingly seen as likely to be of great importance for the protection of natural resources and future food security. Increased consumption of fish, for example, may imply depletion of ocean and freshwater fish resources. Recent initiatives by several Asian nations[1] to purchase or lease land for agricultural production in Africa have raised additional questions about the evolution of food and agricultural policies in Asia. The relationships between intensification of agricultural production (including the production of non-food crops), changes in both climate and the environment, and food security remain poorly understood.

The workshop planning committee brought together a diverse group of experts, including those responsible for key indicators of food security, malnutrition, and poverty; key critics of those metrics; and global agricultural experts. The workshop was structured to broadly reflect the dimensions of sustainable food security—availability, access, and utilization.

The first chapter in Part I addresses issues associated with indicators for measuring food insecurity and malnutrition. It includes a summary of the background paper prepared by Hartwig de Haen, Stephan Klasen, and Matin Qaim. It also includes summaries of presentations on food consumption indicators and malnutrition indicators. The chapter concludes with a summary of the general discussion. Chapter 2 includes a summary of the presentations by Martin Ravallion on the World Bank's poverty measure and James Foster on the new Oxford Multidimensional Poverty Index, followed by notes from the general discussion. Chapter 3 focuses on natural resources and agricultural productivity and includes summaries of on measuring productivity and natural assets; on composite indicators for sustainable production; and on food security and the environment. Summaries of the general discussions are also included. Chapter 4 includes a summary of a proposal made by Prabhu Pingali of the Bill and Melinda Gates Foundation to establish a peer review process for ensuring the reliability, transparency, and quality of the data and methodologies that are used to generate indicators of global food insecurity, hunger, and poverty. The chapter concludes with sample suggestions from participants for strengthening existing indicators and metrics and for making them more accessible.

The organizers of the workshop recognize that the content of the workshop and this summary report leave out many important and relevant metrics associated with food security,

[1] Many others are also involved in leasing or purchasing agricultural land in Africa, including Gulf oil-producing countries and multinational corporations.

poverty, and agricultural production. However, the time constraints of a two day workshop forced the planning committee to limit the number of metrics that could usefully be examined. Hopefully, some of these important metrics including the Household Food Insecurity Access Scale and various measures of dietary diversity developed by the World Food Program, as well others, can be reviewed in other workshops or future meetings.

1

METRICS FOR FOOD INSECURITY AND MALNUTRITION

WHAT DO WE REALLY KNOW? METRICS FOR FOOD INSECURITY AND MALNUTRITION[1], [2]

Hartwig de Haen and Stephan Klasen, University of Göttingen

Hartwig de Haen and Stephan Klasen summarized their background paper, which examines three key methods of assessing food insecurity and malnutrition: (1) the United Nations (UN) Food and Agriculture Organization (FAO) indicator of chronic undernourishment, (2) indicators derived from household consumption surveys, and (3) anthropometric measures. They illustrated the dimensions of food insecurity (Figure I 1-1), reviewed the discrepancies and complementarities between indicators, and offered recommendations for improvement.

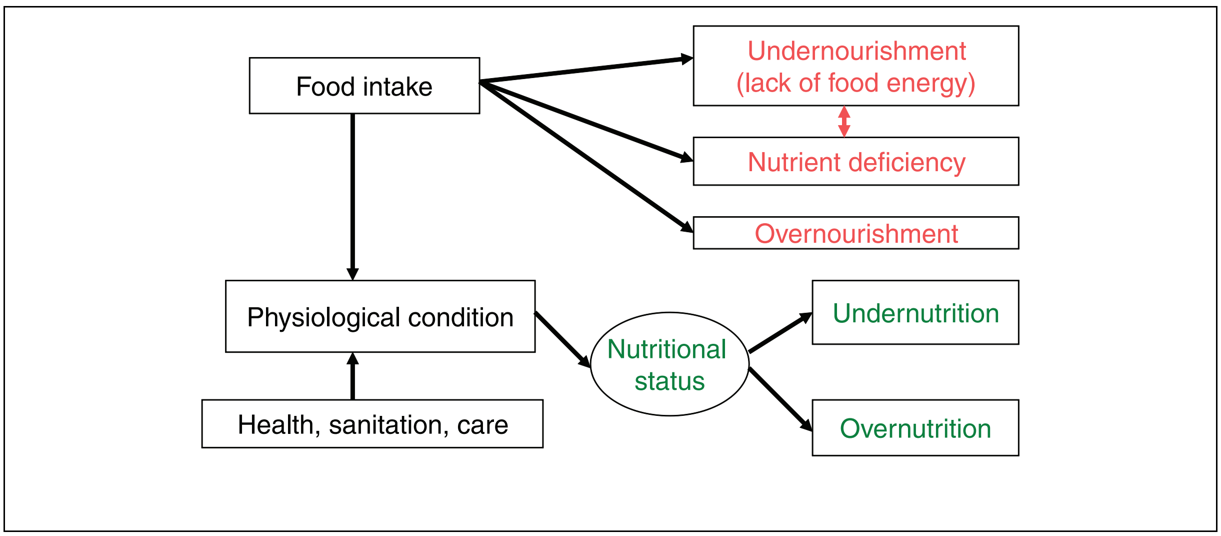

FIGURE I 1-1 Dimensions of food insecurity.
NOTE: Food Security ≠ Nutrition Security; FIVIMS—Multiple Indicators Needed
SOURCE: Presentation by Hartwig de Haen, University of Göttingen, February 16, 2011.

[1] The complete background paper authored by de Haen, Klasen, and Matin Qaim is included in Appendix D.
[2] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_060826, presentation by Hartwig de Haen and Stephan Klasen (February 16, 2011).

The FAO indicator—This indicator is based on national level food balance sheets. It is published annually and, among other things, is used to monitor the Millennium Development Goal (MDG) for hunger. It estimates on a global scale the number of persons in a country whose daily food availability does not provide the minimum amount of energy (kilocalories). It can be criticized for (a) the possibility of errors in food balance sheets caused by uncertain data received from national level data inputs and (b) possible biases in the parameters used to reflect the inequality of consumption within countries (the coefficient of variation). de Haen and Klasen concluded that the FAO method, in principle, was sound theoretically, but that there were major uncertainties and gaps in the data base, so that at present its accuracy is very much open to question. Also, it does not generate actionable information to identify and monitor priorities at the national and sub-national levels.

Food consumption surveys—Nationally representative household surveys are an increasingly important source of data on food security. They are being conducted more frequently and with rising accuracy. Information on food consumption is derived by converting food expenditure information into consumption quantities and calories. Surveys provide a more direct assessment of food energy deficiency at the household level, compared to the FAO method, and provide direct measures of the intra-national inequality of food intake. As with the estimates derived from food balance sheets, household surveys may face problems with data accuracy. There are also concerns about their high cost, timeliness, coverage, and comparability between countries and over time.

Anthropometric measures—These measures are based on nationally representative surveys such as the Demographic and Health Surveys (DHS) or integrated household expenditure surveys (e.g., living standard measurement surveys). They may include anthropometric measurements for all household members, or only for children under a given age (often for children less than 5 years of age), or for women and young children in the household. The data for children are compared to an international reference standard (WHO, 2006) to derive prevalence rates of stunting (low height-for-age), wasting (low weight-for-height), and underweight (low weight-for-age). They are actionable indicators that can be used to target specific interventions and to monitor changes in nutritional status as well as responses to programs and policy changes. There is increasingly good coverage of these indicators internationally and comparability between countries (especially for indicators derived from the DHS). One of the limitations of this indicator is that it is often collected only on children—and, in many cases, their caregiver (such as in the DHS). The data are also usually not collected yearly, preventing the monitoring of short-term trends. The DHS surveys also fail to gather data on important covariates such as income, although integrated household expenditure surveys that collect anthropometric data do have information on total expenditure (a good proxy for income). One advantage of anthropometric data is that they can also be used to derive indicators of overweight and obesity and provide some information on the nutrition transition. But there are also questions about their comparability over time and between countries. In particular, the nutrition transition leading to heavier children may erroneously suggest improvements in underweight (the key MDG indicators), and the method is extremely sensitive to assumptions about even small genetic differences in height and weight potential among populations.

Recommendations from the Authors

de Haen and Klasen first emphasized that each of the indicators discussed above have its particular strengths and weaknesses (Table I 1-1). As a result, a key recommendation is to first work towards a suite of indicators that draws on the respective strengths of each approach. A first step in that direction is to be more transparent about the methods for calculating the measures, and to assemble information in one place (e.g., a Web site) that allows immediate comparisons using all the measures used. Moreover, de Haen and Klasen made several recommendations for improving the FAO indicator, namely, strengthening the food balance sheets data, updating the coefficients of variation, and resuming estimates of the depth of hunger. They also suggested expanding living-standard measurement surveys and possibly linking them to anthropometric surveys (or adding anthropometric measurements where possible). In addition, they recommended using these surveys to derive additional nutrition indicators such as dietary diversity (e.g., using food expenditure modules) and overweight and obesity indicators (using anthropometric measurements of household members), and expanding surveys to include indicators of micronutrient deficiencies (e.g., biomarkers). de Haen and Klasen emphasized that food security is not synonymous to nutritional security, and that both types of indicators should be generated. That is, nutritional security depends not just on food intake but also on physiological condition, health, sanitation etc. They also noted that the common metrics used to assess food insecurity are often inconsistent and focus on chronic food insecurity and on deficiency of energy (kilocalories), ignoring the important dimension of dietary quality. Different metrics are needed to assess the effect of short term price rises and supply disruptions as well as to gauge the magnitude, type, and depth of hunger and to develop appropriate policy responses.

As next steps, they suggested establishing an on-line inventory of various indicators and taking steps to enhance the empirical databases. They also recommended a number of institutional reforms, including encouraging key agencies to cooperate in overcoming incompatibilities between methods and advocating and promoting country owned measurements and policy responses.

TABLE I 1-1 Performance of Three Assessment Approaches as Currently in use with Respect to Different Criteria

Criterion	FAO approach	Consumption survey	Anthropometry
Ability to draw a regular picture for total global, regional and national populations	++	-	+
Ability to draw a regular picture for special population groups at global level	-	-	++
Usefulness to assess inequality of food consumption within countries	--	++	--
Usefulness to assess consumption consistent with national supply and demand	++	-	--
Accuracy in terms of measuring the adequacy of food intake	+	++	--
Accuracy in terms of measuring and identifying determinants of nutritional status at a point in time	-	+	++
Accuracy in comparing nutritional status across space and over time	--	+	?
Ability to assess dietary diversity and micronutrient status	--	++	-
Ability to portray regional and socioeconomic heterogeneity within countries	--	++	++
Ability to portray seasonal variation	--	-	-
Ability to inform global governance	++	-	++
Usefulness to guide national policy decisions (e.g., targeting)	--	+	++
Usefulness to simulate nutritional impacts of policies and shocks at country level	--	++	-

NOTE+ and – signs indicate whether or not the approach is suitable. Double signs indicate very suitable or very unsuitable.

SOURCE: Presentation by Hartwig de Haen, University of Göttingen, February 16, 2011.

FOOD CONSUMPTION INDICATORS: FAO CHRONIC HUNGER INDICATOR[3]

Pietro Gennari, Food and Agriculture Organization

Pietro Gennari outlined some of the major criticisms of the FAO measure. He cited concerns about the appropriateness of FAO's operational definition of hunger, the soundness of the methodology, and the reliability of the data used to compile estimates. He talked about new

[3] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_060826, presentation by Pietro Gennari (February 16, 2011).

demands for information at national and subnational levels as well as by socio-economic groups, interest in tracking changes in hunger to income growth and poverty reduction, and real time monitoring in response to food price changes.

Gennari explained that the FAO prevalence of undernourishment (PU) indicator is based on two fundamental assumptions:

- Nourishment refers to food intake, not to the consequences of metabolic food processing.
- Food intake can be properly measured through the amount of dietary energy.

FAO's PU is an indicator of chronic hunger; that is, it captures the evolution of fundamental elements that drive long term nutritional status. As such, it is not intended to capture the impact of seasonal food shortages or temporary food price crises, unless such events have long lasting consequences. He noted the need for additional indicators to measure, for example, the impact of price volatility on food security.

Gennari also discussed the FAO methodology, described in Box I 1-1.

FAO is currently working on a comprehensive revision of its methodology. Gennari cited the major issues being addressed:

Improvement of food balance sheets (FBS) estimates. The amount of food available in a country is a very important indicator in its own right and not just an input into measuring undernourishment. It measures one of the key dimensions of food security as defined by the World Food Summit in 1996. A program of revision of the FBS parameters and technical coefficients used to estimate the diverse uses of food items for non-human consumption and their conversion into nutrients has been undertaken. A system for regularly updating these parameters also needs to be put in place. In the longer-term, FBS estimates will benefit from improved basic agricultural data through a new initiative of statistical capacity development (the Global Strategy to Improve Agricultural Statistics) recently launched by FAO in partnership with other international and regional organizations.

Whenever possible, make systematic use of household survey (HS) data to estimate the mean and coefficient of variation (CV) of the dietary energy consumption (DEC) distribution, and compare them with the parameters used in the past. This activity also contributes to the objective on reconciling estimates of food availability from FBS and HS.

BOX I 1-1
Theoretical Considerations and Implementation

FAO follows a *parametric* approach based on postulating a probability model for the level of individual dietary energy consumption (DEC) in the population, as opposed to a possible nonparametric approach based on the measure of the relative frequency in a sample of people found to consume less than their requirement. The parametric approach has the advantage of allowing for a better comparability and aggregation of the estimates obtained for different countries.

In the practical implementation of FAO's parametric approach, key choices (which have been subject to criticisms) are the following:

1. **Choice of the most appropriate model for the marginal distribution of DEC**. In practice, FAO has been using a lognormal distribution for DEC. The choice has been admittedly guided by desirable properties of the statistical model (flexible, yet parsimonious) though a number of tests in the past have consistently failed to reject it as a legitimate one.
2. **Method to estimate the parameters of the marginal distribution of DEC.**

- **The Mean**. FAO has traditionally used the mean per capita dietary energy availability as derived from food balance sheets (FBS) data and after converting food available into calories. It has been proposed that, where available, estimates of mean per capita food consumption obtained from household surveys (HS) be used instead. Since household budget surveys of good quality are now frequently available and with a good country coverage, FAO plans to use both FBS and HS for the same country and, if needed, year-after reconciliation of the estimates obtained from the two sources.
- **The Coefficient of Variation**. As opposed to the mean, the only possible source of data for estimation of the coefficient of variation (CV) of DEC is survey data. One debated issue is whether survey data can be used for a direct estimate of CV or if an indirect method needs to be devised. According to FAO, direct estimates of variance from household surveys are likely to be biased because of higher variability in samples than in the population, for various reasons, including that survey rounds are usually spread across the year and the likely presence of outliers, missing data (e.g., food consumed away from home), and so on. To avoid the problem, FAO has devised an indirect method based on clustering individual households' data to eliminate unwarranted variability.

3. **Method to estimate the cut-off level of the minimum dietary energy requirement (MDER)**. In estimating the MDER, DER depends on the basic metabolic rates of individuals, which vary with sex, age, and the level of physical activity. Normative values on the acceptable ranges of energy requirements are given for groups of same sex-age by expert nutritionists. The minima of those ranges compatible with a light physical activity level are averaged across the sex-age composition of the population to provide a single estimate of MDER

Additional tests and refinement of the parametric model, which includes performing new tests of the lognormality of the DEC distribution and devising proper methods for interpolation and extrapolation of the estimate of the prevalence of undernourishment (based on observed evolution or on projected values of income, price, and population) for producing revised time series of country-specific PUs, and real time global PU estimates, even before actual data on food consumption are available.

Production of additional indicators. In view of broadening the scope for information on food security and nutrition, as a first step FAO proposes the following additional indicators, which could be easily produced given the available data: (1) prevalence of over-nourishment, (2) prevalence of population under food stress (minimum dietary energy requirement corresponding to an economically active life), and (3) depth of food deficit (amount of energy that would be needed to ensure that hunger would be eliminated).

Improved communication, to allow users to understand the specific analytic objectives and theoretical basis of each of the indicators, to provide measures of uncertainty associated with point estimates, and to resist publication of estimates when based on data that are deemed unreliable. The overall aim is to consolidate FAO's role as the main contributor to the monitoring of food security, by developing a platform for dissemination of a comprehensive set of food security indicators and related background information to serve the needs of analysts and policy makers.

FAO UNDERNOURISHMENT INDICATOR: STRENGTHS AND WEAKNESSES[4]

Benjamin Senauer, University of Minnesota

Following the Gennari presentation, Ben Senauer reiterated the basic elements of the FAO methodology for estimating the number of food insecure persons, which is based on three key components. The first component is the average calories available per capita, the dietary energy supply (DES), based on national food balance sheet data. The second is the distribution of calorie consumption across the population, for which a log-normal function is assumed and a CV derived from household survey data is utilized. The third is an average minimum calorie requirement for the population, based on gender and age, which establishes a cut-off point on the distribution for undernourishment.

Senauer described some of the strengths of the FAO indicator. The measure serves as an important, annual benchmark of progress towards reducing chronic hunger, or the lack thereof, assuming it has the right trend. With the FAO indicator, food insecurity can be monitored at the global, regional, and national levels, and the same methodology is used for every country. He noted that the FAO indicator relies on the accuracy of the three major components, with food balance sheet data as the foundation. National food balance sheets, also referred to as food disappearance or food availability data, form the foundation for FAO's estimates. They start with an estimate of a country's production by crop, based on estimates of the area harvested and yield. The quality of these estimates almost certainly varies enormously between a country like Norway and the Congo. The supply of a crop is equal to production plus imports and beginning

[4] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_060826, presentation by Benjamin Senauer (February 16, 2011).

stocks, minus exports. Disappearance or utilization must then balance (equal) supply. Disappearance includes seed and feed use, ending stocks, government purchases, and a "residual", which balances supply and utilization. This residual is assumed to have been "consumed" or is available for consumption. The aggregate availability is divided by national population to get per capita availability. The calories across all crops and animals can then be summed to get the total dietary energy supply (DES) per capita. This result depends on many separate estimates within the food balance sheet.

Senauer discussed the difficulties inherent in converting the crop or animal supply at the farmgate into what is available as retail-level food products and accounting for losses during transportation, storage, and processing. For example, the U.S. conversion factor for converting beef carcasses to retail beef is 0.76, and 0.689 for boneless, which means 76 percent of a beef carcass is assumed to end up at the retail level, or 68.9 percent when leaving out the bones. The determination of the conversion factor can be very complicated, when considering the hundreds of different food products that a crop like wheat is used for. In addition, to get to the DES utilized for the FAO estimates, losses at the household level must be accounted for, such as losses during home storage and cooking and uneaten food. In conclusion, Senauer asked how reliable are food balance sheet data for deriving FAO's undernourishment estimates.

OUTCOME INDICATORS: MEASURES OF MALNUTRITION[5, 6]

Lynnette M. Neufeld, Micronutrient Initiative

Lynnette Neufeld began her presentation by explaining that collecting information on the nutritional status of populations is necessary to characterize the magnitude and distribution of deficiency, to identify subgroups at risk, and to design, implement, and monitor interventions and programs that can address nutritional problems and their direct and indirect causes. Several indicators are used at the population level to serve this purpose, including anthropometric measures (physical size, growth over time, and age), dietary intake, and biomarkers of micronutrient status. She commented on some of the strengths and weaknesses of anthropometric measures and the use of physiological biomarkers when assessing the nutritional status and health of populations.

Anthropometric Indicators

Neufeld talked about the use of size as a reflection of the growth process and its use as a proxy for health status because it is strongly associated with mortality and morbidity risk, impaired cognitive development in children, and adverse pregnancy outcomes. Examples of such measures are illustrated in Table I 1-2. She noted that the potential height of an individual is determined by genetics, but actual size and rate of growth depend on whether potential is limited by inadequate nutrition and illness. Growth of an individual can only be assessed with multiple

[5] Presentation prepared in collaboration with Blair Cameron, Research Associate, Micronutrient Initiative.
[6] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_060826, presentation by Lynnette Neufeld (February 16, 2011).

measures over time; single measures assess size, which can be interpreted in comparison to what is expected in a healthy individual for a given age.

TABLE I 1-2 Metrics for Assessing Malnutrition

Weight Height	Low		Adequate		High	
	Micro-nutrient sufficient	MN deficient	MN sufficient	MN deficient	MN sufficient	MN deficient
Low	Stunted Wasted	Stunted Wasted	Stunted Adequate weight	Stunted Adequate weight	Stunted Over weight	Stunted Over weight
Adequate	Adequate height Wasted	Adequate height Wasted	Adequate height Adequate weight	Adequate height Adequate weight	Adequate height Over weight	Adequate height Over weight

SOURCE: Presentation by Lynnette Neufeld, Micronutrient Initiative, February 16, 2011.

Height below what is expected for age is an indicator of chronic nutritional status. Weight-for-height reflects the extent to which the body's soft tissues (muscle and fat, principally) are proportional to their size (height) and is thus a reflection of short term or acute nutritional status. In older children and adults, the body mass index (BMI) (weight [kg]/height [m^2]) is often used to reflect the appropriate proportion between body mass (soft tissue) and height (WHO, 2006). A third indicator, weight-for-age, has been used to provide a reflection of the overall nutritional status of an individual but without distinguishing between compromised growth due to undernutrition (low height) and current or acute malnutrition (low weight-for-height). Nor can weight-for-age distinguish among individuals who may be tall and thin (e.g. high weight-for-age and height-for-age but low weight-for-height) and those who are short and adequate- or even high-weight proportional to their height. Other measures of child size can provide context to weight-for-age, including height-for-age, an indicator of long-term nutritional status, and weight-for-height and mid-upper arm circumference (MUAC), both indicators of short-term nutritional status. Therefore, weight-for-age has limited utility to distinguish between the likely causes of nutritional problems and provides no clues as to the types of interventions that might be needed to alleviate them.

Neufeld noted that the World Health Organization's (WHO) Global Database on Child Growth and Malnutrition compiles information on all four anthropometric indicators of nutritional status: height-for-age, weight-for-age, weight-for-height, and BMI-for-age (WHO, 2006). However, the utility of these indicators for informing policies and programs at a country level relies on the availability of this data being systematically collected and its accuracy, as well as the availability of information related to the potential causes of any observed deficits. The only one of the four indicators that is widely collected by numerous countries is the prevalence of low weight-for-age. This is due at least in part to ease of measurement and because it is a key indicator for monitoring progress towards the Millennium Development Goals. Despite the limitations mentioned above, this information allows for comparison within and across regions and countries over time (United Nations, 2010).

Biochemical Indicators

Neufeld explained that the utility of anthropometric indicators to provide a complete reflection of the nutritional status of a population is further complicated by the potential for concurrent micronutrient deficiencies, even in an apparently well-nourished group. Biochemical indicators or biomarkers are used to detect a deficiency before clinical signs appear, requiring biological samples most commonly in the form of blood or urine. Biomarkers of micronutrients may reflect exposure (dietary intake), status (nutrient reserves), or function (improved or compromised performance of a system).

There has been some progress in improving the availability of sensitive and specific biomarkers of micronutrient status. The U.S. National Institutes of Health are currently leading an initiative entitled Biomarkers of Nutrition for Development (BOND). BOND focuses on clarifying the uses of biomarkers for different user groups (research, clinical, policy, and programs applications), identifying the strengths and weaknesses of current biomarkers to meet the needs of those groups, and promoting the research and technological innovations needed to strengthen them.

Indicators of exposure, such as dietary assessment, can also provide information on the *risk* of inadequate intake and of resulting micronutrient deficiencies. Dietary intake assessment methods, Neufeld noted, can be time- and resource-intensive, but simple measures of dietary diversity (e.g., number of food groups consumed in past 24 hours) have recently been shown to be useful predictors of the probability of inadequate intake of micronutrients in children and in women of reproductive age (Arimond et al., 2011). These simple indicators can be collected through large, nationally representative surveys such as the DHS or the integrated household expenditure surveys and generate useful information on the risk of poor diet quality and micronutrient deficiencies in certain population groups.

Conclusions

Neufeld concluded that there have been many improvements in the quality and availability of information on the nutritional status of populations in recent years. The inclusion of anthropometric measures in large national surveys (e.g., DHS and Multiple Indicator Cluster Surveys) has been particularly helpful for this purpose. However, many countries still have information only for global malnutrition (i.e., prevalence of low weight-for-age), which is insufficient to accurately reflect nutritional problems in countries. At this time, no single indicator of nutritional status can adequately reflect the complex problem of poor nutrition. It is unlikely that any single indicator will ever be sufficient to reflect long and short term overall adequacy of dietary intake and the sufficiency of micronutrient intake in individuals or populations. Multiple indicators are needed to reflect both the adequacy of food intake (e.g. height and weight) and its quality (nutrient content of foods or biochemical indicators of micronutrient status).

MEASURES OF OVERNUTRITION AND OBESITY[7]

Ricardo Uauy, University of Chile

Ricardo Uauy began his presentation with a set of photographs illustrating the problem of using just weight or a Body Mass Index (BMI) to determine overnutrition or obesity in adults. He explained that the location where fat is stored, in the abdomen or not, is more important than weight by itself. Abdominal fat (belly fat) is associated with changes in lipid metabolism leading to higher levels of LDL cholesterol (bad cholesterol), lower levels of HDL cholesterol (good cholesterol) and higher levels of sugar in the blood, these changes result in increased risk of heart disease and diabetes respectively. Alternatively if fat is stored in other parts of the body buttocks; it is less harmful. A BMI is calculated solely on the basis of height and weight and therefore is not a direct measure of body fat, nor does it indicate where the fat has been deposited (as illustrated in Figure I 1-2).

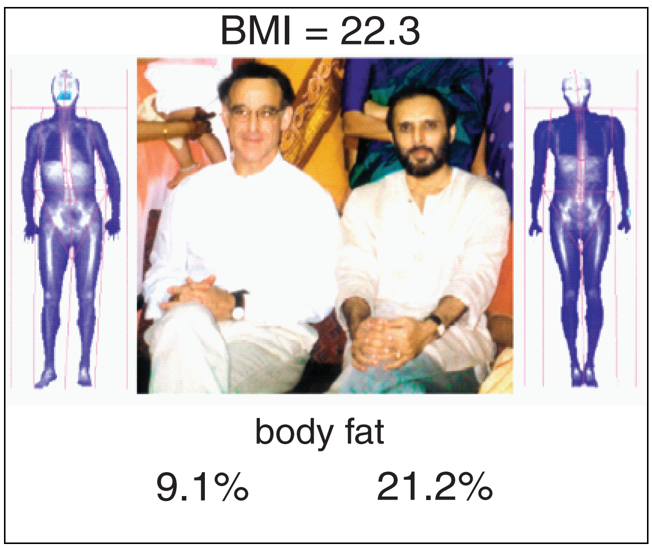

FIGURE I 1-2 BMI and percent body fat.
SOURCE: *The Lancet* 363, January 10, 2004.

Furthermore, Uauy stated, standard cutoffs, such as a BMI greater than 25 to indicate elevated risk associated with overweight, may not be appropriate in all countries. A lower value (e.g., 23 rather than 25) might be more appropriate in many Asian countries, since these populations have increased metabolic complications when the BMI exceeds this value.

While the use of BMI is not a perfect indicator, it is useful in assessing long term consequences of overnutrition and obesity. Data suggest that in all regions of the world there have been very significant increases in BMI levels, with slightly higher increases for women

[7] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_060826, presentation by Ricardo Uauy (February 16, 2011).

than for men. The highest rates of obesity (BMI over 30) occur in the United States and in Oceania, with rates of obesity reaching 30 percent of the U.S. population in 2009. Uauy noted that WHO did not recognize obesity as a public health problem until the late 1990s, but it is now widely seen as a critical public health issue in developed and many developing countries.

Uauy also discussed some of the specific challenges associated with childhood malnutrition. He explained that often stunted children who are short and underweight for age but not underweight for their height are given supplementary food in an attempt to make them grow. However, if this increased energy intake does not contain sufficient micronutrients, children gain weight in excess of normal for their height, leading to obesity and "metabolic syndrome" when they reach adulthood. He noted that the government of Mexico is addressing the problem of undernutrition in the right way, providing high levels of micronutrients and only 10-20 percent of daily energy needs in its supplemental feeding program.

In conclusion, Uauy emphasized some of the short comings in the BMI measures, but he maintained that the survey data used to measure the BMI were strong and that what we need now are measures of physical activity that could be used in conjunction with the BMI to assess long term health risks. Abdominal circumference can be used as a reasonable proxy for metabolic alterations associated with metabolic syndrome. The possibility of documenting the blood changes in lipids and sugar in a sub-sample of the population may be considered if resources are available.

GENERAL DISCUSSION

Shahla Shapouri, U.S. Department of Agriculture, and
Adelheid Onyango, World Health Organization

Shahla Shapouri and Adelheid Onyango began the general discussion. Shapouri talked about the need to have information on food stocks in use and not to treat stocks as a residual. She explained that there appear to be significant discrepancies between calories per capita using food balance sheets versus household surveys. She emphasized the need for policy makers to have access to timely data to understand the impacts of food price rises on food security for different population groups (e.g., urban versus rural, net producers versus net consumers, etc.). She noted that all measures of global hunger are estimates and thus can be challenged. Shapouri suggested that it is necessary to have a balanced approach, recognizing the trade-offs between perfecting the data and methodology and providing timely data for policy makers. She also stated that there are a lot of additional data being generated by the UN World Food Program and the U.S. Agency for International Development (USAID) Famine Early Warning Systems. Network that could supplement the FAO data, providing more comprehensive data to policy makers.

Onyango explained the long term importance of child nutrition, noting that in the first 2 years, growth is sensitive to nutrient intake and infections, and this period is the critical "window of opportunity" to intervene to prevent malnutrition. By age 2-3 years, stunting (deficit in attained height) has happened, and reversal is extremely difficult thereafter. Early stunting is also associated with life-long negative consequences, such as poor cognitive development, school performance, reproductive capacity, and economic productivity at adulthood.

Countries have been most successful at monitoring underweight because the equipment is the most accessible and the skills required are easily attained. However, in populations with high stunting prevalence, the normalization of weight-for-age happens when stunted children become overweight. This carries serious implications for chronic diseases (e.g., starting at school age, metabolic syndrome).

WHO recently published a set of key indicators that are now subject to public review, shown in Box I 1-2:

BOX I 1-2
Key Indicators

Outcome indicators: Low birth weight; malnutrition derived from anthropometry in under 5 children, 5-19 year old children/young adults, women of reproductive age, obese adults), anemia in women of reproductive age, etc.

Process indicators of program implementation: Infant and young child feeding indicators, Baby-friendly Hospital Initiative, immunization coverage, vitamin supplements to children under 5 years of age, iodized salt consumption, access to treatment and ready-to-use therapeutic food for children with severe acute malnutrition.

Food security indicators: Dietary energy intake, measures of dietary diversity, measures of household expenditure on food, poverty headcount ratio at $1.25 a day.

Policy environment indicators: International code of marketing breast milk substitutes, strength of nutrition governance (very soft), staff with nutrition skills at different levels of service delivery.

SOURCE: http://www.who.int/nutrition/EB128/en.

Unfortunately, data for these indicators are often lacking or are unreliable, but it would be useful to have them to answer the variety of questions and interests that policy makers may have, including the following:

- The impacts of investments in human capital on food security, poverty, and nutritional status
- Monitoring trends in different nutrition problems in nations or in areas of endemic micronutrient malnutrition
- Forecast of future nutrition-related chronic diseases that have important implications in terms of economic and healthcare costs

- Feasibility and cost implications are often the factors that weigh most on decisions to collect and analyze the data to generate these indicators.

OTHER COMMENTS

Emmy Simmons noted that the FAO indicators are "supply driven," when what is needed are systems that are more "demand driven," that is, designed to meet the needs of policy makers at national and subnational levels. Participants also discussed the importance of developing better quality national level data—a key input to the global metrics as well as for assessing local conditions. A number of participants discussed the growing role of household surveys as a complement to food balance sheets and other data used for food security indicators. It was noted that it would be useful to make such surveys more comparable across countries. At the same time, some participants expressed concern about the long term "sustainability" of these surveys given expected reductions in donor budgets used to fund many of them, such as the USAID funded Demographic and Health Surveys.

Marie Ruel made a point about the so called Asian enigma—high levels of underweight or malnourished children despite substantial economic growth in recent years. She noted that the Asian enigma has been described as a problem largely due to the women's poor *physical* and *social* status in some Asian countries, which results in small mothers giving birth to small babies (who suffer from malnutrition in the womb), who then are exposed to unsanitary environments and sub-optimal feeding practices and care during early infancy (mothers may have insufficient breast milk or milk of inadequate quality due to malnutrition, and may lack the means to purchase adequate complementary foods for their young children). These factors are compounded by social norms that may lead to girls being less likely than boys to be fed adequately or to be taken to preventive or curative health care services and less likely to go to school and by girls being likely to marry and start having children during adolescence (which affects their own growth and health). All these factors lead to a cycle of poor physical growth and ill health transmitted from one generation to another, which is unlikely to be resolved by economic growth alone and requires specific actions to enhance women's social status, decision-making power, and access to—and control over—resources.

Hartwig de Haen and other participants stressed the need for making data and indicators more widely available, possibly creating a portal with an on-line inventory. Over the long term the improved transparency and accessibility could lead to improvements in national level data and provide possibilities for more research and quantitative analysis.

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2

MEASURES OF GLOBAL POVERTY

MEASURES OF NATIONAL AND GLOBAL POVERTY AND THEIR USE IN POLICY MAKING: WORLD BANK POVERTY MEASURES[1]

Martin Ravallion, The World Bank

Martin Ravallion described the World Bank's approach to measuring global poverty, explained the progress that had been achieved in various parts of the world to reduce poverty, and then discussed some the challenges ahead. He explained the difficulties inherent in defining a single global measure of poverty. He added that most of the World Bank's poverty measurement and analysis activities are, in fact, done at a country level to inform local government policies and programming decisions by the World Bank.

He noted that it is difficult to talk meaningfully about global income poverty, since poverty lines across countries vary in terms of their purchasing power, and there is a strong economic gradient with richer countries adopting higher standards of living for defining poverty. In the poorest countries, poverty lines tend to reflect "absolute poverty," with minimal requirements for food and non-food needs. In richer countries they reflect a measure of "relative poverty," with more generous allowances for consumption needs; these lines are often set at some percentage of the country's mean or median income.

Ravallion explained that the $1 a day global poverty measure was an attempt to measure poverty in the world as a whole and to assure that two people with the same purchasing power over commodities are treated the same way even if they live in different countries. He suggested that focusing on the standards of the poorest countries gives a salience to the world's poorest people that would not exist if higher poverty lines were used.

Based on the World Bank's level poverty assessments and the results of the 2005 international comparison project, new poverty rates were recalculated. Overall the percentage of people falling below a poverty line of $1.25 a day was halved between 1981 and 2005 from 52 to 26 or a numerical decline from 1.9 billion to 1.4 billion (Figure I 2-1). However, there are stark regional differences, with huge progress in China and substantial progress in India. Poverty rates have also fallen in Latin America, the Caribbean, the Middle East, and North Africa; however, the total numbers of those in poverty in these regions have not declined. And in Eastern Europe

[1] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_060826, presentation by Martin Ravallion (February 16, 2011).

and Central Asia, poverty rates and numbers of poor people have increased, although there have been signs of progress since the late 1990s.

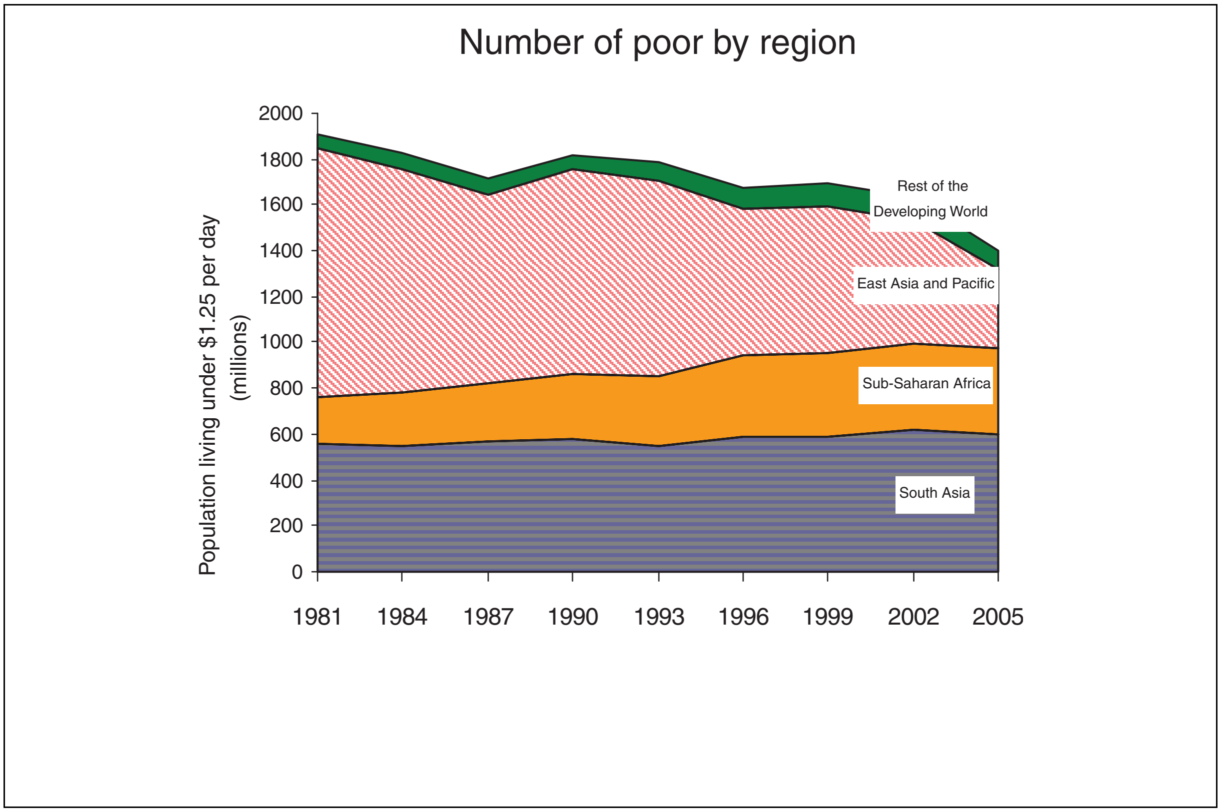

FIGURE I 2-1 The regional picture: Uneven progress.
SOURCE: Presentation by Martin Ravallion, The World Bank, February 16, 2011.

The situation in Sub-Saharan Africa stands out with little change in poverty rates and substantial increases in the number of people deemed poor using the $1.25 a day poverty line for 1981–2005. The number of poor has almost doubled between 1981 and 2005, increasing from 200 million to 380 million. Furthermore, Ravallion noted that there is a greater depth of poverty in Sub-Saharan Africa, with the mean consumption of the poor estimated at only 70 cents a day, making it the lowest in the world. However, he also noted that there have been encouraging signs of greater progress against poverty in Africa since the mid-1990s.

Challenges Ahead

Household surveys. During the last 10 to 20 years, there has been a huge expansion in the coverage of household surveys, expanding from just 22 countries in 1990 to 116 countries in 2011. Coverage is especially good in East Asia, South Asia, Eastern and Central Europe, and Latin America, but lagging in the Middle East and North Africa and Sub-Saharan Africa. Furthermore, in the Middle East and North Africa region there is no public access to the data, unlike in other regions. Despite the increase in coverage, there are continued concerns about lags in data availability and public access, comparability over time and across countries, and underreporting and selective compliance.

Ravallion explained that market exchange rates generally are not useful in assessing real incomes in developing countries, in that they tend to equate purchasing power with traded goods. Therefore the International Comparison Project has developed more realistic estimates of purchasing power parity exchange rates. The latest ICP data were released in 2005 with a new one scheduled for release in 2011. Despite improvements in the ICP process since the 1970s, serious issues remain in that they tend to be urban biased under representing rural areas, which is a particular concern in China, where only 11 cities were surveyed.

Ravallion also discussed the arguments in favor of relative poverty lines. He noted that many Organization for Economic Cooperation and Development countries have relative poverty lines, that is, a fixed proportion of the country's mean or median income. He suggested that one way to allow for relative poverty is to have a poverty line that is constant at very low incomes—representing absolute poverty—and then increasing at somewhat higher incomes.

Ravallion concluded by noting that in most instances there is no need to form a single composite poverty index that includes data on nutrition, child mortality, schooling, and violence, as these indicators are too disparate to combine into a single measure. The ultimate goal should be to create a set of multiple indexes that looks at these non-consumption factors and can usefully guide policy makers, rather than develop a single multidimensional index.

OXFORD MULTIDIMENSIONAL INDEX[2]

James E. Foster, The George Washington University

James Foster described the recently released Oxford Multidimensional Poverty Index (MPI). He explained that this type of index was needed because conventional measures of poverty capture only an income or consumption dimension of poverty, when in fact there are many other aspects of poverty. He suggested that such a measure must be understandable and easy to describe as well as conform to common-sense notions of poverty. It must also be technically solid and data must be available. While such indexes have been talked about for some time, one impetus for the new index came from Mexico, where a government law mandates that poverty be measured multidimensionally.

The new index provides a dual cutoff approach to measuring poverty. Within each dimension there is a deprivation cutoff, and then across the dimensions there is a poverty cutoff. That is, if someone is deprived in enough dimensions or in enough breadth, they are considered poor. Foster described the approach as being intuitive, transparent, and flexible. He emphasized its use in country applications, where one can target and evaluate policies. He also said that it was participatory, in that country stakeholders could determine cutoff and weights rather than having a one-size-fits-all index. The three specific dimensions included in the MPI are education, health, and standard of living, and there are 10 associated indicators (Box I 2-1).

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[2] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_060826, presentation by James Foster (February 16, 2011).

BOX I 2-1
Multidimensional Poverty Index Indicators

Education (Each indicator is weighted equally at 1/6)

- Years of Schooling: Deprived if no household member has completed 5 years of schooling
- School Attendance: Deprived if any school -aged child is not attending school in years 1 to 8

Health (Each indicator is weighted equally at 1/6.)

- Child Mortality: Deprived if any child has died in the family Nutrition: Deprived if any adult or child for whom there is nutritional information is malnourished

Standard of Living (Each indicator is weighted equally at 1/18.)

- Electricity: Deprived if the household has no electricity
- Drinking Water: Deprived if the household does not have access to clean drinking water or clean water is more than 30 minutes walk from home
- Sanitation: Deprived if they do not have adequate sanitation or if their toilet is shared
- Flooring: Deprived if the household has a dirt, sand, or dung floor
- Cooking Fuel: Deprived if the household cooks with wood, charcoal, or dung
- Assets: Deprived if the household does not own more than one of the following: radio, TV, telephone, bike, motorbike, or refrigerator, and does not own a car or tractor

SOURCE: http://www.ophi.org.uk/wp-content/uploads/MPI-One-Page-final.pdf.

PANEL DISCUSSION

Marco Ferroni opened the panel discussion, encouraging participants to focus on four key issues:

- How important are global numbers for hunger, malnutrition, and poverty? For whom?
- Do measures of poverty, food security, and malnutrition move in the same direction? If not, why not? Is this a problem with the measures or does it highlight more complex issues?
- Are numbers comparable between countries and over time?
- What information do decision makers really need and for what?

Stephan Klasen began the session by focusing on three points. First he noted that the $1 a day measure of global poverty is not a direct measure of food or nutritional security. In fact, the relation between income and nutrition is not clear. Second, the dollar a day measure was revised upward in 2005 resulting in dramatic increases in poverty in both China and India despite substantial economic expansion in both countries. He noted that this may have been the result of changes in the way purchasing power parity numbers were calculated rather than any real change in poverty rates. Third, he suggested that poverty measures and food security measures are closely related at a country level, even if they are not at a global level. That is, national level poverty lines are often nutritionally based. In addition, Klasen suggested that if there was enough trust in the data generated through household surveys it would be possible to actually compile a more accurate global poverty number—basically, the sum of the country level numbers. Even in this case, though, such a measure does not reflect intrahousehold issues, that is, how food supplies are allocated within a household. This is an important consideration, in that we can often find malnourished children in a household with well nourished adults. Klasen also talked about the usefulness of the MPI in shifting discussions about poverty beyond simply income and consumption. He noted that it was easy to criticize the MPI—how the weights were chosen, cutoff points, aggregations, and even what was included—but it has started a valuable debate.

Martin Ravallion added that he agreed that poverty is multidimensional, but argued against a single index, suggesting that a composite index masks the real data that are needed to take action and that one of the first things a decision maker is likely to do with the MPI is to unpack the data.

Workshop participants discussed household surveys and the extent to which they could be made more comparable across countries and the degree to which these surveys could be expanded to include questions on food security and nutritional status. While some participants suggested that the surveys should be expanded, Ravallion stressed the need to identify a basic core set of data requirements that can be implemented well in all developing countries, with the possibility of conducting other more specialized ad hoc surveys.

Other participants suggested that it might be possible to more directly link poverty and nutrition measures in household surveys, but that it would require substantially increased training for the enumerators and that in some countries—India and China were specifically mentioned—it would be very difficult, as the survey instruments are already considered too long and response rates are declining sharply, limiting the usefulness of the survey data. Lynnette Neufeld suggested that it was important to understand what the indicators would be used for in order to determine local priorities. Rather than try to stretch a survey or multiple surveys and expect that they will be used in the same manner across all countries, she said that data requirements need to be based on a clear understanding of the national policies and decisions that will be driven by the data.

Other workshop participants expressed concern about the timeliness of the poverty data and the inability to measure transitory poverty, both critical inputs for policy makers.[3]

[3] An extensive bibliography of articles assessing an array of global poverty measures is included at the end of Part I of the report.

3

NATURAL RESOURCES AND AGRICULTURAL PRODUCTIVITY

Chapters 1 and 2 looked at metrics related to the demand side of food security—poverty and food consumption and outcome measures. This chapter changes course and looks at supply-side aspects of sustainable food security, summarizing presentations and discussions about measuring agricultural productivity and natural assets, examining composite indicators for sustainable production and natural resource use, and the effect on the environment of achieving food security.

MEASURING AGRICULTURAL PRODUCTIVITY AND NATURAL ASSETS

This first section examines a variety of metrics associated with changes in agricultural productivity and natural assets. Richard Perrin describes two standard productivity measures—single and multiple factor productivity and then links these to projects of future food demand to illustrate the extent to which productivity must expand in the coming decades. A second presentation links spatially explicit measures of agricultural productivity and eco-system services. Steve Polasky then describes approaches to measure changes in the value of eco-system services resulting from land use changes. The final presentation talks about various metrics associated with the supply and use of water resources for agriculture.

APPROACHES FOR MEASURING PRODUCTIVITY AND NATURAL ASSETS PRODUCTIVITY METRICS VERSUS FOOD SECURITY[1, 2]

Richard K. Perrin, University of Nebraska–Lincoln

Productivity

Richard Perrin explained that the basic definition of productivity is output divided by input. He noted that the *growth* of productivity is more important than any particular level itself. Single-factor productivity, such as tons of wheat per hectare, is conceptually straightforward. A more comprehensive measure is multiple-factor productivity (MFP), defined as an index of

[1] Prepared jointly with Lilyan E. Fulginiti, University of Nebraska–Lincoln.
[2] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_060826, presentation by Richard Perrin (February 16, 2011).

outputs over an index of inputs. MFP is complex and subject to many different measurement approaches. The productivity numerator includes only measurable outputs that contribute to human welfare, and the denominator considers only measureable inputs that we think are important.

Productivity growth can help gauge progress toward future food security, given the limited potential for increasing resources. For the food producing sector, Perrin noted, these basic resources include land, water, and natural resources and critical factors such as climate and ecological resilience. The supply of other inputs, including labor and chemicals, seems to be in sufficiently elastic that they would not hinder food security in the future. It is the basic resource productivity that will matter.

Growth in Food Demand versus Growth in Productivity

Comparing projected growth in food demand with growth of productivity is one useful way to frame the issue of food security. A commonly accepted estimate of the increase in food demand by 2050, developed by the United Nations Food and Agriculture Organization (FAO), is 70 percent (Table I 3-1).

TABLE I 3-1 World Food Demand Growth, 2010-2050

Source of Growth	Total Increase (%)	Annual Rate of Increase (%)
Population growth	32	0.7
Income growth	38	0.8
Total increase	70	1.34

SOURCE: Presentation by Richard Perrin, University of Nebraska–Lincoln, February 16, 2011.

Conceptually, a productivity growth rate of 1.34 percent is not a necessary condition for achieving the 70 percent goal. But this growth rate implies that 70 percent more could be produced by 2050 with the *current resources* devoted to agriculture. If the growth rate were lower, additional resources would be required if demand growth were to be met.

Trends in Measured MFP versus a Goal of 1.34 Percent

World agricultural productivity growth rates, both single factor productivity (grain yields) and multifactor productivity have been relatively stable for the past 15 years, at a rate very near the 1.34 percent goal. Though the MFP growth rate has increased since the 1960s, the rate of growth for grain yields has declined since the 1960-1980 period, as shown in Figure I 3-1.

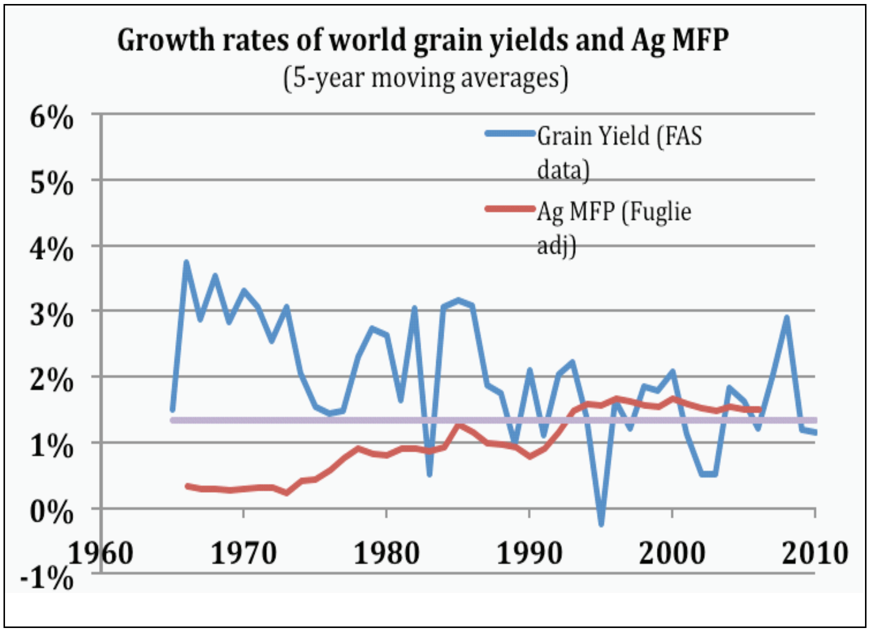

FIGURE I 3-1 Crop yields versus MFP—world.
SOURCES: Authors' calculations from USDA FAS data, Fuglie (2008).

If the 1.34 percent growth target for productivity alone is not met, additional resources will be required. Such resources can be attracted into agriculture only if food prices rise, jeopardizing food security for some. Growth trends for cropland and irrigation do not encourage optimism for new resources.

Conclusions

Perrin stated that world agricultural productivity growth rates are perhaps declining slightly, but in recent years they appear to have been sufficient to provide security in 2050 if they were to persist. He also noted that it is not certain that these rates will persist, and unfortunately, the available measures of MFP are not measures of the productivity of those resources that are most likely to be limiting—land, water and natural resources.

EXPANDING AGRICULTURAL PRODUCTIVITY MEASURES AND LINKING TO ECOSYSTEM SERVICES—A SPATIALLY EXPLICIT APPROACH[3]

Stanley Wood, International Food Policy Research Institute

Stanley Wood described a new project, HarvestChoice,[4] which is developing a set of spatially explicit measures of agricultural productivity and ecosystem services, as well as indicators of poverty and hunger. The goal of the project is to examine the links between hunger, poverty, and agricultural productivity measures and ultimately to improve long-term agricultural productivity, increasing human welfare. The project focuses on Sub-Saharan Africa and South Asia, where productivity increases have stagnated over the past decades.

Wood described some of the key variables included in the project, beginning with the agricultural base: slope, aspect, drainage, and elevation; location of settlements, ports, and markets; and basic infrastructure, such as roads and information and communications technology. This layer is then overlaid with data on the incidence of pests and diseases as constraints to agricultural productivity and the incidence and severity of droughts and surface runoff. This collection of data provides a way of understanding and characterizing the production environment, which can then be combined with data illustrating the biophysical suitability of different types of crops.

The project also includes detailed information on the location and extent of human welfare metrics, which can be analyzed together with the agricultural productivity information described above. Wood showed a map of Africa illustrating the extent to which rising rural population density is increasing stress on critical natural resources (Figure I 3-2).

In summary, he noted that spatially explicit variables have a key role to play in understanding the where and why of hunger, poverty, and productivity measures. They provide a way to understand the interplay of human welfare, agricultural production, and ecosystem services as well as to evaluate specific interventions.

Wood acknowledged that there are a number of spatial data issues. For example, maps give the illusion of precision and accuracy, and the reliability of remotely sensed data is not always strong. However, the data may be good enough—fit for the purpose of strengthening the evidence base to make key decisions.

[3] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_060826, presentation by Stanley Wood (February 16, 2011).
[4] Funded by the Bill and Melinda Gates Foundation and conducted by the Institute for Food Policy Research (IFPRI) and the Center for International Science and Technology Practice and Policy at the University of Minnesota.

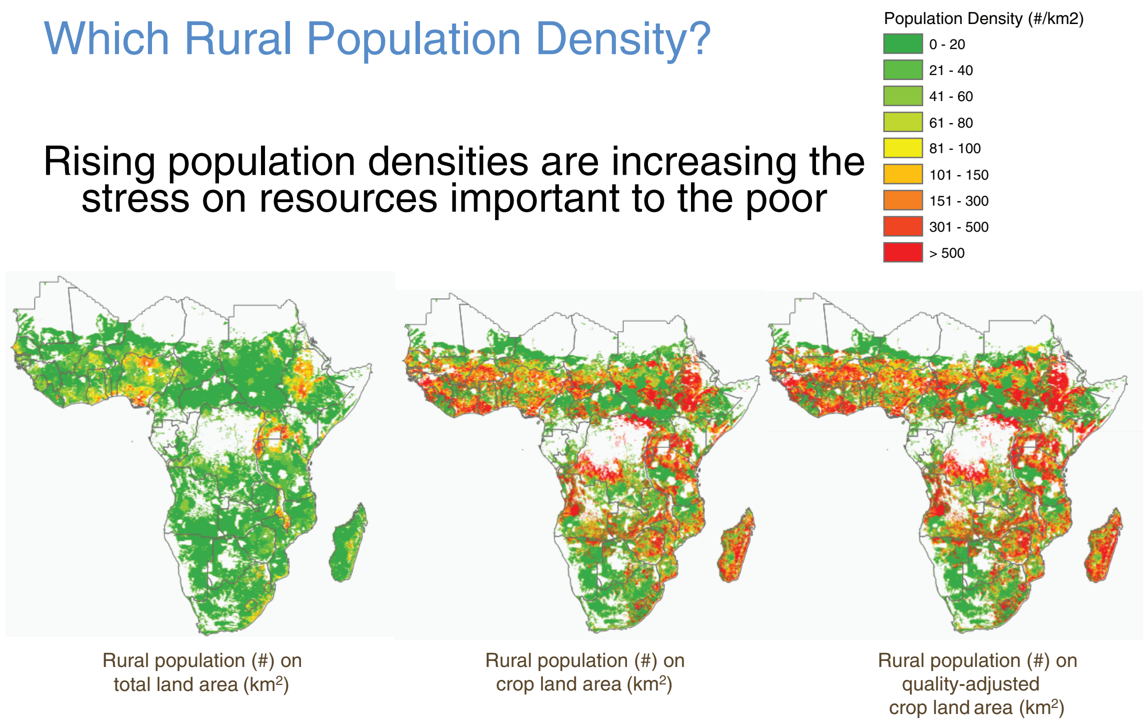

FIGURE I 3-2 Which rural population density?
NOTE: White-masked areas include inland water bodies, protected areas, urban areas, irrigated areas, closed forest, and land not suited for pasture or rainfed crops.
SOURCE: HarvestChoice, 2010.

MEASURING PRODUCTIVITY AND NATURAL ASSETS: MEASURING AND VALUING NATURAL ASSETS[5]

Stephen Polasky, University of Minnesota

Steve Polasky explained that ecosystems, including agricultural systems, provide a wide variety of goods and services to people. Examples include food, water quantity and quality, carbon sequestration, recreation, and aesthetics. Land use and land management decisions result in both intentional and unintentional affects on the bundle of services provided. However, these effects are generally not factored into decision making, because monetary values are not assigned to most ecosystem services. This can result in the loss of services valuable to the environment and human society. He stressed the importance to sustainability of being able to make good decisions about future land use and the need to look at trade-offs. He noted that relying on the market system is not sufficient; it is necessary to pay attention to ecosystem services that are not valued in the market place. Furthermore, the ecological data necessary to value ecosystem services are very limited.

[5] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_060826, presentation by Steve Polasky (February 16, 2011).

Polasky described activities undertaken through the Natural Capital Project's InVEST[6] to develop a set of tools integrating the value of ecosystems services and highlighting potential trade-offs. The tool is based on a set of computer-based models, including biodiversity and other ecosystem services. It is spatially explicit and driven by future scenarios. It is also flexible and transferable. Polasky noted that the tool is data intensive and that ecological data are limited. He remarked that eco-data collection is much less advanced than the poverty and nutrition data cited in the earlier workshop sessions.

The InVEST tool has been used in Minnesota to compare impacts on ecosystem services and biodiversity from actual changes in land use between 1992 and 2001 with alternative scenarios. For example what would have been the likely impacts if there was no agricultural expansion or urban expansion etc. The analysis focused on the following: ecosystem services—water quality and carbon sequestration; biodiversity—grassland bird habitat, forest bird habitat, and general biodiversity; and return to landowners from agricultural production, timber production, and urban development. He presented a series of slides illustrating how alternative land-use scenarios affect each of these key variables and the need to have a complete set of metrics (e.g., Figure I 3-3).

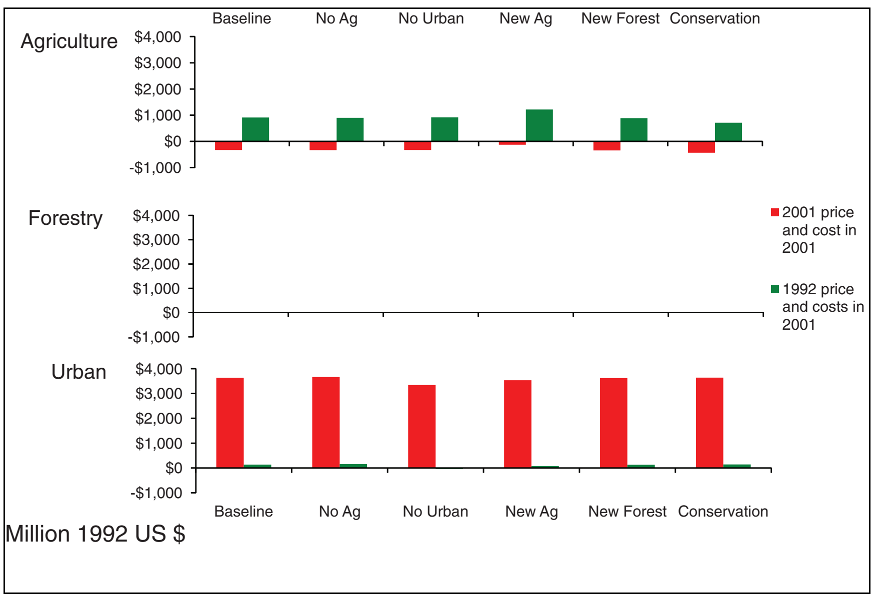

FIGURE I 3-3 Change from 1992 to 2001 by scenario: Market returns to agriculture, forestry, urban areas.
SOURCE: Presentation by Steve Polasky, University of Minnesota, February 16, 2011.

In summarizing the presentation, he noted that incorporating the value of ecosystem services in land use decisions can result in a higher level of services being provided as well as a higher value of total goods and services. He also noted that agricultural land use changes have a far bigger effect on ecosystem services and biodiversity than do changes in urban land use.

[6] See http://www.naturalcapitalproject.org/InVEST.html. Accessed on March 30, 2011

WATER, AGRICULTURAL PRODUCTIVITY,AND ENVIRONMENTAL SERVICES[7, 8]

Peter G. McCornick, Duke University

Peter McCornick stated that food security is inherently dependent on the availability of water resources, whether it is reliable rainfall (green water) or irrigation from surface or groundwater sources (blue water). Competition for water from urban areas, industry and higher value agricultural products will require that lower value, staple crop production rely more heavily on rainfall or depend increasingly on less reliable blue water sources or both. Projected population growth, expanding demand for a diet higher in animal products and fish, and the increased need for non-food crops, including those for bioenergy, will continue to increase the demand for water from agriculture. McCornick noted that the quantity of water from rainfed and irrigated sources required by the agricultural sector is expected to as much as double by 2050, further disrupting ecosystems.

Agricultural Water Productivity

To achieve food security and yet mitigate the negative effects on water resource systems requires that water productivity be increased. However, saving water is not enough if there is not a system for allocating it appropriately to achieve both productivity objectives and distributional objectives. Therefore, effective governance systems and institutions must be developed. Not all water apparently saved can be reallocated. Moreover, McCornick stated that effective governance mechanisms are required to reallocate any gains that are made.

Trade-offs and Scale

McCornick explained that the rice-wheat systems in the Indus and Ganges basins provide an example of intensified use, trade-offs, and unintended consequences. The yields in the relatively water short Punjab portion of the basin are already high. Efforts to improve water conservation in this area through various water resource conservation technologies (i.e. zero tillage for wheat, direct seeding, bed planting, laser land leveling and crop residue management) improved the field level water productivity. However, this “saved” water at the field scale resulted in the expansion of irrigated crop-land in the immediate area, while the available supply downstream declined highlighting the potential for unintended tradeoffs, especially critical in increasingly water scarce basins in the developing world, such as the Indus.

Food security is a function of water security, especially in terms of water availability and reliability. Disrupting this relationship are flood and drought events, which are expected to become more frequent and severe as agricultural production expands and intensifies in flood

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[7] Prepared in collaboration with David Molden, Deputy Director General of Research, International Water Management Institute, Colombo, Sri Lanka.
[8] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_060826, presentation by Peter McCornick (February 16, 2011).

prone areas, while other regions suffer from a paucity of rainfall. Climate change further complicates the situation. Decision making related to food security must carefully consider water resources, especially to identify regions where there is the opportunity to increase agricultural productivity without further stressing water resources (i.e., more crop-per-drop). McCornick noted that this is especially critical in an increasing number of major agricultural producing areas, where water is already relatively scarce. While most experts are optimistic that there is scope for water productivity gains, such gains are difficult to realize and require a holistic view of water management. Water allocation and reallocation processes are required in addition to farm scale practices to realize gains of water productivity. To mitigate these consequences, an essential tool in food security enhancement is accounting for water resources and management, including actual water use in irrigated and rainfed areas, and the impact on available water resources downstream. Unfortunately, many of these challenged regions are relatively data scarce, the quality of information that does exist varies, and many of the data sets have been developed as part of specific projects and are often not accessible at the national and sub-national scales, which are crucial to water related decision making. Fortunately, technological advances are presenting opportunities to better assess crop water use and groundwater levels.

GENERAL DISCUSSION

Hartwig de Haen began the discussion by questioning the extent to which agricultural productivity must be increased in order to meet increases in population and food demand by 2050. He suggested that some of the assumptions underlying the projection that would require a 70 percent increase in production of food and feed would depend on other factors and drivers of total future need for agricultural commodities. For example, he questioned whether future food consumption trends will include increasing shares of animal protein as in recent years, whether the amount of crops used for non-food uses such as biofuels will continue to grow, and whether levels of post harvest losses and excessive food use will continue. He suggested that scenarios should also be considered to explore the implications if these assumptions shifted: The required production increases could be lowered, and the stress on natural resources could be reduced. Bill Jury encouraged the group to consider long term demographics changes, such as increases in urban populations in attempting to assure sufficient food supplies where they are needed.

Phil Pardey noted that the discussion on metrics for poverty and food security was retrospective, not spatial and not forward looking, whereas the discussion on agricultural productivity was forward looking and spatial.

COMPOSITE INDICATORS FOR SUSTAINABLE PRODUCTION

The panel examined composite indicators for sustainable production and natural resource use and reviewed their use in promoting sustainable practices and in providing information to consumers and policy makers.

OVERVIEW OF METRICS AND INDICATORS, DIFFERENT APPROACHES, AND STRENGTHS AAND WEAKNESSES[9]

Greg Thoma, University of Arkansas

Greg Thoma provided a brief description of some of the agricultural sustainability metrics currently available. He explained that sustainable agriculture can be defined as (a) meeting the needs of the present while enhancing the ability of future generations to meet needs, (b) increasing productivity to meet future food demands, (c) decreasing harmful effects on the environment, (d) improving human health, and (e) improving the social and economic well-being of agricultural communities.[10] However, the definition is not tied to any specific metrics and therefore does not provide a basis for action. He suggested that it is necessary to measure the outcome of agricultural production in order to reduce environmental impacts. He identified a set (not exhaustive) of variables critical to understanding agricultural systems, which are listed in Table I 3-2.

TABLE I 3-2 Examples of Agricultural Sustainability Indicators

Category	Emissions		Drivers
Water Quality	Nutrients Sediments Pesticides Antibiotics	Ammonia Metals Hormones Pathogens	Livestock: Manure management & application Storm water management Land management (tillage, etc) Crop protection and fertilization
Water Use	Groundwater scarcity Reduced stream flows impact aquatic habitats		Livestock: Drinking water and facility maintenance Irrigation
Air Quality	Particulate matter (1^0 & 2^0) Odor Ozone precursors Greenhouse gasses		Manure management Animal emissions Combustion
Land Use / Biodiversity	Land occupation and conversion Habitat degradation / fragmentation		Land management (Tillage, riparian zone management, etc.)

SOURCE: Presentation by Greg Thoma, University of Arkansas, February 17, 2011.

Thoma then explained that these metrics need to be built into a framework that will help in understanding the broader agricultural system as well as impacts and trade-offs. One such framework or tool is life cycle assessment. This allows us to (a) think broadly from cradle to next life; (b) think deeply about the impacts and endpoints; (c) think quantitatively throughout the

[9] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_060826, presentation by Greg Thoma (February 17, 2011).
[10] As defined by the Keystone Alliance: Field to Market.

supply chain, accounting for inputs, outputs, and emissions; and (d) think comparatively to understand expectations and make a positive change. He noted that life cycle assessment is a useful but far from perfect tool, in part because it does not yet include spatial or temporal dynamics very well. He mentioned some newer tools, such as InVEST, that can assess the impacts of ecosystem services, but those methods are not yet ready for incorporating into life cycle assessment

Thoma provided a brief overview of some ongoing efforts to develop sustainability metrics, sustainability indicators, and software tools (Box I 3-1).

In conclusion, Thoma emphasized that sustainability metrics should be outcome based and technology neutral so that creative innovators can do whatever makes the most sense in their specific location. Life cycle assessment is a useful tool in that it provides information and understanding, enabling engagement of procurement officers and consumers so that market signals and incentive can be communicated to farmers and other primary producers.

BOX I 3-1
Ongoing Efforts

Sustainability Metrics (Quantitative)

- Field to Market—The Keystone Alliance for Sustainable Agriculture: Focuses on commodity agriculture; metrics are outcomes based and technology neutral; natural and regional in scale.
- Stewardship Index for Specialty Crops: Focuses primarily on vegetables and fruits; metrics are outcomes based and technology neutral; regional and local in scale.
- Solutions from the Land: Focuses on linking crop, forestry, and conservation land-management; metrics into a harmonized approach; sponsored by the United Nations Foundation, Conservation International, the Nature Conservancy, and the Farm Foundation.

Sustainability Indicators (Qualitative)

- Unilever Sustainable Agriculture Code: Mandatory program for Unilever agriculture suppliers; for example, it requires recordkeeping for pest and nutrient management; some simple metrics are included.
- SAI Platform: Focuses specifically on agriculture; provides guidance on best management practices; more practice than outcomes driven.
- People 4 Earth: Broadly looks at supply chains; uses more than 300 qualitative questions that span sectors other than agriculture.

Software Tools

BASF Eco-Efficiency Analysis; GaBi, SimaPro, SALCA (Swiss Agricultural Life Cycle Assessment); carbon footprint calculators (e.g., Cool Farm Tool); Fieldprint Calculator (Field to Market); Global Water Tool; InVEST; and HarvestChoice.

INDUSTRY PERSPECTIVE ON USE OF METRICS[11]

Jennifer Shaw, Syngenta

Jennifer Shaw noted that there is wide agreement that agricultural systems need to be sustainable to ensure long-term food security. The challenge, she said, is in trying to define and measure what this really means. For Syngenta, one of the most important sustainability initiatives in North America is Field to Market (FTM), a diverse stakeholder group facilitated by the Keystone Center in Keystone, Colorado. FTM represents organizations with a common interest in focusing on sustainable outcomes for production agriculture. The philosophy behind FTM is to (a) focus on a key set of outcomes, (b) establish science-based metrics for measuring progress against those outcomes, and then (c) "let the chips fall where they may." With respect to technology, the initiative takes a neutral position, neither promoting nor obstructing it. The presence or absence of a given technology is not the key. The important thing is the performance of the whole system and the tool is being used to develop precise metrics to assess changes in agricultural systems. For example, "How are we doing today, and are we heading in the right direction?"

Field to Market Indicators of Sustainability

- Environmental Indicators
  - Land Use
  - Water Use
  - Soil
  - Energy
  - Climate
  - Water Quality
  - Biodiversity
- Productivity Indicators
- Grower Economic Index
- Social Indicators
- Health Indicators
- Ability to Meet Global Demand

FTM has developed metrics for five of the environmental efficiency indicators listed above (energy, water, climate change, soil and land use/productivity). These metrics are being piloted in cropping systems across the United States. Syngenta has been part of this process.

[11] © 2011 Syngenta Crop Protection, LLC 410 S. Swing Road, Greensboro, NC 27409. The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_060826, presentation by Jennifer Shaw (February 17, 2011)

Guiding Principles and Urgency

Syngenta's sustainability team is working with a set of key principles developed in collaboration with other stakeholders and growers. Important among these principles are that metrics should be:

- Science based & validated
- Transparent & open sourced
- Pragmatic & focused on what matters
- Value creating for the grower (must exceed the cost & disruption)
- Respectful of confidentiality
- Verifiable concerning improvements
- Not disruptive to efficient product movement & relationships
- Focusing on decisions in the control of the grower
- Recognizing & addressing land tenure relationships in creating incentives
- Phased & realistic
- Move with value creation, not in front of it
- Improve over time

The lack of certainty concerning metrics is beginning to hold up adoption both at the producer level and among downstream players. Producers do not know how to think about metrics: opportunity or threat? Downstream companies do not know what is possible: are significant improvements within supply chains really feasible? The path to resolving this uncertainty is not clear, but the urgency is growing.

Framework

Shaw described how Syngenta visualizes the sustainability journey in three basic steps (Figure I 3-4):

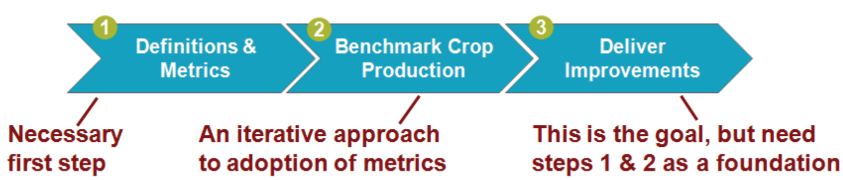

FIGURE I 3-4 Three basic steps for the sustainability journey.
SOURCE: Presentation by Jennifer Shaw, Syngenta, February 17, 2011.

The first and most important step is the establishment of definitions and metrics. After metrics have been developed and a degree of consensus forms among producers and downstream users, the next step will be to benchmark production regions.

The benchmarking process may take several years to compete. Both temporal and spatial variability will be significant. A broad view (many areas over multiple years) will likely be needed to develop a clear understanding of what really drives the system and how best to make meaningful improvements. Some "low hanging fruit" can be expected in the early years, especially in making efficiency improvements (e.g., less energy, water, carbon, etc. per unit). Other more complex metrics will take time to understand and interpret.

Insights from Sustainability Pilots

Shaw explained that Syngenta incorporated the FtM metrics into one of their leading on-farm management systems, Land.db™, and introduced the metrics to growers during the last growing season. The TLand.db™ tool allowed growers to run scenarios with the FTM metrics, testing the impact of various cropping decisions on their environmental indicator score as it compared to neighbors as well as the state and national averages. They expressed great interest in this feature. Growers also liked having the metrics integrated with the farm management tool they had already deployed.

Field to Market

In addition, Shaw noted that the tool also highlighted previously non-obvious areas of potential improvement (e.g. energy associated with use of certain farm practices). Two major issues were also highlighted during the pilot process: (1) the time required to enter quality data were significant (3-4 hours per farm even when facilitated by an expert) and (2) the perception of value varied greatly among growers (significant suspicion exists about the future impact of the metrics, and data privacy was a prevalent & significant concern). Shaw stated that these issues will need to be addressed before things will move forward on a meaningful scale. Most importantly, strong grower incentives will need to be in place from the outset. The costs and potential disruption to the grower are significant. If value does not exceed costs, resistance can be expected.

Concluding Remarks

In summary, the important insights include:

- Leveraging existing systems and relationships are possible.
- Significant effort is required to gather data (esp. at field level).
- If readily usable, the FtM metrics would inform operational decisions on a routine basis (field by field).
- Aggregated data will help support the environmental benefit of certain production practices over time.
- Going forward, data can be used to support life-cycle inventories for crop production on a regional and local basis.
- Grower time & costs are significant—adequate incentives are essential.
- Many of the basic insights are likely applicable to other regions.
- Certainty around metrics is critical to get things moving.

EXPERIENCE ON GATHERING MEANINGFUL DATA FOR LIFE CYCLE ANALYSES: THE BASF ECO-EFFICIENCY TOOL IN INDIAN AGRICULTURE[12]

Dirk Voeste, BASF Crop Protection

Dirk Voeste presented details on how key indicators and data can be used to effectively measure sustainability over an entire life-cycle. He shared information gleaned from a unique case study carried out in India to assess soybean production.

While soybean is a key source of edible oil in India, overall productivity is low in comparison with the world average. Initiated in 2007 as a BASF farmer training project in the Indian Guna region, Samruddhi is a holistic business approach to help farmers and their communities to improve productivity and become more sustainable. The idea, Voeste said, is simple: educate farmers and demonstrate good agricultural practice, find ways to boost farm yields and profitability, show how product stewardship programs can be implemented, and offer hands-on advice. By 2009, over 100,000 farmers had successfully participated in the program.

To assess the sustainability impact of the Samruddhi program, BASF conducted a detailed Eco-Efficiency Analysis looking at two pillars of sustainability, namely, the economic and ecological factors. Voeste noted that some of the data also related to social aspects of sustainability. As he explained, the initial step in any such study is to set the correct system boundaries. In this case, boundaries for comparing Samruddhi with traditional farmer practice

[12] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_060826, presentation by Dirk Voeste (February 17, 2011).

focused exclusively on the production of soybeans. The Eco-Efficiency Analysis included indicators on energy consumption, land use, resource consumption, emissions, toxicity potential, and occupational diseases and working accidents. The life-cycle assessment[13] used average data points, collected from farmer surveys, eco-profiles from BASF proprietary and commercial databases, and farmer occupational risk data from an Internet search of publicly available information. Data on toxicity and eco-toxicity potential were sourced from Material Safety Data Sheets (MSDS) and additional factor calculations based on publicly available data sources.

In a study of this kind, for weighting purposes, the relevance of each indicator is fully assessed, using statistics and relevant data points from publicly available sources. Societal factors are then applied, gleaned from public polls and expert studies. To further illustrate the study results, the final report summarizes the main findings by showing each indicator as well as the relative impact of each indicator category, clearly represented through diagrams.

The results of this study, Voeste noted, validate that Samruddhi's cultivation of soybeans is significantly more eco-efficient (greater than 5 percent) for both the economy and the environment, when compared to traditional farmers practices in India. The program delivered higher yields (double the Indian average), lower cultivation costs, and lower environmental impacts in comparison with traditional farming practices. Apart from water emissions and toxicity potential, Samruddhi scored better on all the key indicators—yield, cost, energy consumption, air emissions, land use, and risk potential to farmers. In terms of identifying measures to improve sustainability, the study indicated the negative potential of the fertilizer being used, which led to a search for a new solution. Voeste also acknowledged that there is scope for further yield improvement, as the soybean yield for Samruddhi still remains significantly lower than the world average.

At a macro level, the study demonstrated that it is possible to objectively measure sustainability. Importantly, a number of different parameters can be tested and the consequences assessed. Voeste emphasized that these scenarios are a very valuable methodology to support informed decision making and drive positive change towards an improvement in sustainable agriculture. While the study highlighted that BASF's methodology had the potential to become a valuable decision tool for politicians and the entire food chain, the company also recognized the tool's limitations. As Voeste pointed out, the current set of indicators in the Eco Efficiency Analysis, used for the Samruddhi study, do not support the measurement of biodiversity, specific soil indicators, or other indicators being of high importance for agricultural production systems. This has encouraged BASF to work on an enlarged indicator set specifically for applications in agriculture. The testing phase for the new method, called AgBalance, is nearly closed—BASF is currently running a first demonstrator study. Other studies will follow by summer 2011.

Voeste pointed out the critical importance of incorporating practical scenarios. He argued that this type of analysis highlights improvement potential and facilitates effective decision making. For credibility and acceptance, the tool has to be validated by recognized institutes as well as stakeholders.

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[13] A life-cycle assessment (LCA) is a technique that is used to assess the environmental aspects and potential impacts associated with a product, process, or service, by: compiling an inventory of relevant energy and material inputs and environmental releases; evaluating the potential environmental impacts associated with identified inputs and releases, and interpreting the results to help people make more informed decisions. http://www.epa.gov/nrmrl/lcaccess. Accessed on June 6, 2011.

Voeste closed his presentation by outlining key points. In his view, the fundamental principle has to be science-based analysis. A holistic and multicriteria approach is necessary to demonstrate the impact on all aspects of sustainability. Researchers cannot rely on a single indicator or a small group of indicators. Instead, a comprehensive set of robust and relevant indicators are essential, together with reliable and quality data sources. Otherwise, the study runs the risk of drawing incorrect conclusions or conclusions that do not cover all the relevant aspects. To correlate the used indicators, publicly acceptable weighting factors have to be used, and the results need to be quantitative and replicable.

Voeste emphasized that the improvement of relevant indicators—used to assess and monitor progress in sustainability—will be vital in the global effort towards sustainable food security. Robust measurement and practical scenarios will facilitate governance and drive appropriate change.

FOOD SECURITY AND THE ENVIRONMENT

Jason Clay of the World Wildlife Fund set the stage for this session by stating that in the next 40 years (i.e., by 2050), we will have to produce as much food as has been produced in the last 8,000 years, and we are already exceeding the carrying capacity of the planet's resources. He noted that water is a critical concern going forward and that we need to find ways to address increasingly scarce and variable water resources. Agriculture is also a large polluter (air, water, and greenhouse gas emissions), which has more negative impacts on the planet than any other human activity. He suggested that another noticeable factor is food waste—from the farm level to consumers and beyond. Therefore, one of the most efficient ways to increase food availability is to reduce waste. Clay also suggested that in this context, nature, not government, is the single largest source of subsidies for agriculture. Furthermore, we need to account for environmental externalities in costs and prices to send the right signals to producers and consumers. Finally, Clay suggested that whatever the sustainability challenges have been to date, they will increase significantly by 2050, when we have more than 9 billion people, with an average of 2.9 times as much income, a doubling in consumption, and an increase in the consumption of animal protein. This is the challenge going forward.

FOOD SECURITY AND THE ENVIRONMENT: FOOD SECURITY AND LAND CROPPING POTENTIAL[14]

Jonathan Foley, University of Minnesota

Jon Foley began by emphasizing the role of agriculture on the planet, noting that about 40 percent of our global land area, 70 percent of our global water withdrawals, and 30 percent of our greenhouse gas emissions come from land use and agriculture. It is also the single largest driver of biodiversity decline. Therefore, it will be a major challenge to meet future food demands while at the same time minimizing environmental impacts.

[14] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_060826, presentation by Jon Foley (February 17, 2011).

Foley noted that there are two ways to meet these growing demands: expand the area under production that grows food or intensify production per unit area of land (or both). Each has serious environmental consequences. Expansion has significant implications for carbon, climate change, and biodiversity. Intensification, on the other hand, requires the increasing use of water resources, nutrients, pesticides, and fossil energy.

Foley described the Global Landscapes Initiative,[15] based at the University of Minnesota, which has developed approaches to examine these environmental implications and trade-offs. The initiative provides spatial data on yields, fertilizer use, and irrigation rates of more than 175 crops. Foley's presentation also focused on global production patterns for maize and wheat, suggesting potential areas for agricultural expansion and intensification. He noted that further cropland expansion is possible, but that many of the most likely areas are in the tropics or other sensitive ecosystems, often with lower rates of productivity, so that carbon debt and the biodiversity implications are enormous (Figure I 3-5).

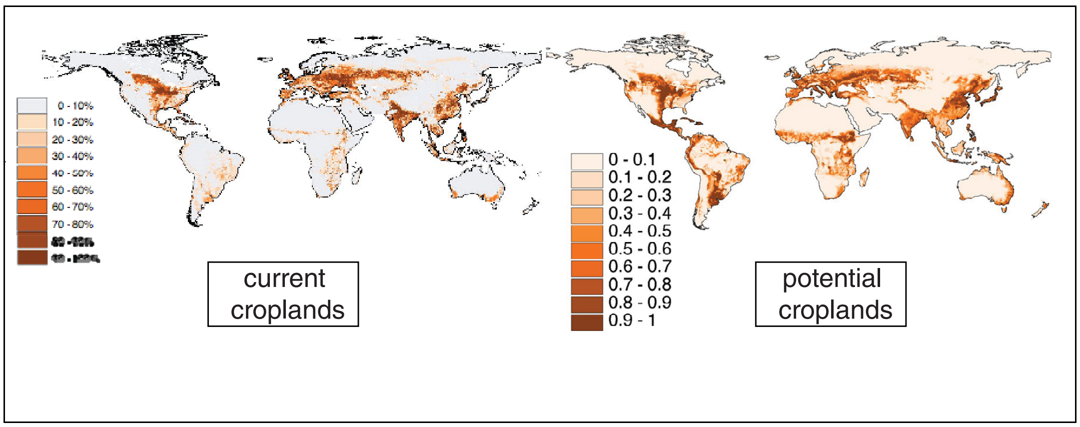

FIGURE I 3-5 Further expansion is possible.
SOURCE: Presentation by Jon Foley, University of Minnesota, February 17, 2011. Ramankutty et. al. 2002.

The map in Figure I 3-6 shows maize yields around the world to help identify areas where more intensive cultivation could result in large productivity gains. The green areas are places where close to maximum yields have been achieved (e.g., U.S. Upper Midwest and Spain). In many places (colored yellow and brown), productivity could be increased by 25–50 percent without genetic improvement. He singled out Eastern Europe as a region with significant potential for increased yields with improved management and infrastructure. Current production is now just 25 percent of what would be projected based on its climate and soils.

Foley identified water and nutrient availability as the most significant short term factors limiting production growth. Over the longer term, genetic improvements would be necessary.

[15] See http://environment.umn.edwateru/gli. Accessed on June 6, 2011.

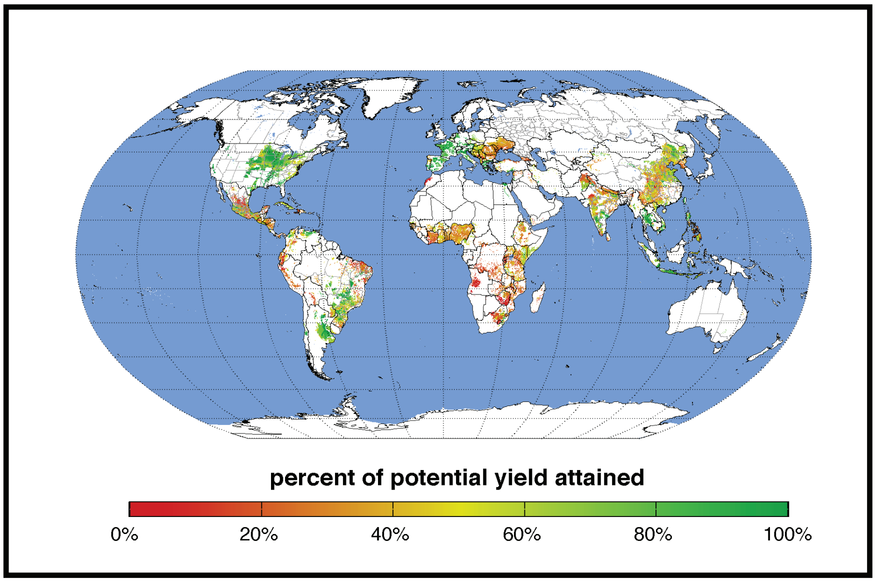

FIGURE I 3-6 Maize yield attainment.
SOURCE: Presentation by Jon Foley, University of Minnesota, February 17, 2011. Data from Mueller et. al., in preparation.

In conclusion, Foley noted that freezing the footprint of agriculture; sustainably intensifying land; optimizing the trade-offs between yield, water, and nutrients; and dramatically improving the efficiency of the entire food system will be important steps. He emphasized the need not only to look at food production as an end point but also to look at the net nutritional contribution resulting from our agricultural practices.

THE ENERGY AND CARBON CONUNDRUM IN SUSTAINABLE AGRICULTURAL PRODUCTION[16]

Paul Vlek, University of Bonn

Paul Vlek noted that growth in population and income in the developing world is driving an increase in demand for food and agricultural production, calling for more land to be converted or existing agricultural land to be used more intensively. This pressure has led to an increase in land dedicated to agriculture in its various forms of around 20 percent over the last 40 years of the past century with more than 50 percent of the tropical regions suffering from land degradation and half of this area also showing serious soil degradation. Projections show that

[16] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_060826, presentation by Paul Vlek (February 17, 2011).

another 20-30 percent of the original biomes in the tropics will be converted to agricultural land by the middle of this century. As a result of land conversion it is estimated that about 2,250 10^6 metric tons of carbon dioxide (CO_2) are emitted in the tropics alone. Thus, land conversion is an environmentally costly means of securing food for a growing population.

Since the early 1960s, agricultural intensification has been an increasingly important means for meeting food demand. In fact, Vlek stated, this approach is credited with sparing 1.1 billion ha of land that would have been converted if intensification options had not been available. However, intensification of agriculture has been based largely on the deployment of fossil energy in the sector. As annual primary energy use worldwide climbed from 9,000 to 10,000 10^6 toe[17] during the 1990s, fossil energy use in agriculture went up from 197 to 222 10^6 toe, with most of that increase occurring in Asia. As agricultural systems become more intensive, the energy efficiency of these systems decreases. As a result, the United States and Europe produce 1.1 and 1.7 calories of food, respectively, for every calorie of fossil energy used, whereas this ratio is nearly 5 in developing countries. If human energy is taken into account, the efficiency of transforming energy into food calories is widely different, varying from 16.5 for mixed root-crop-based systems in New Guinea to 1.3 for intensive rice cultivation in Surinam. Thus, intensification has led to a great dependence of agricultural production on fossil fuels, a rather disconcerting dependency when sustainability of agriculture is increasingly called for, given the finite amounts of fossil fuels. The annual CO_2 emission associated with this fossil energy use is estimated to amount to 200 10^6 t, or one-tenth of what is emitted as a result of land conversion, two-thirds of it associated with fertilizer use and one-third associated with the use of mechanization. Thus, though less costly in greenhouse gas emissions, the long-term prospects of relying on fossil energy for food production are risky.

Vlek explained that, overall, the contribution of agricultural operations to greenhouse gas emissions is fairly small. It is the clearing of native ecosystems for agricultural use in the tropics that is the largest (non-fossil fuel) source of CO_2 input to the atmosphere. The use of farm machinery, irrigation, fertilization, and chemical pesticides amounts to merely 4 percent of commercial energy use in developing countries. Of this, 70 percent is associated with the production and use of chemical fertilizers. In the absence of fertilizer use, the developing world would have converted even more land for agriculture, most of which is completely unsuitable for long-term cultivation. The dynamics of land appropriation by agriculture and pastures is driven by increasing food demand, but also by the loss of productive land due to degradation. The need to curtail encroachment on new, often less suitable land comes at a great cost, both in loss of ecosystem services and CO_2 emission, and should be avoided. However, the land that is threatened to be abandoned due to degradation may make a contribution in mitigating greenhouse gas emissions. Current expectations are that reforestation on such land can sequester large quantities of carbon to mitigate excessive emissions elsewhere. But any program that aims to set aside marginal land for the purpose of sequestering carbon must do so without threatening food security in the region. The best option to liberate the necessary land for carbon sequestration would be the intensification of agricultural production on some of the better lands by increased fertilizer inputs while, at the same time afforesting some of the non- or less-productive land. The validity of this concept has been demonstrated in experiments in Uzbekistan, where as much as 120 metric tons of carbon were sequestered over 4 years by trees planted on highly salinized agricultural land.

[17] Tons of oil equivalent.

Vlek explained that his calculations show that the sequestration of carbon through afforestation far outweighs the emissions that are associated with the production of the extra fertilizer needed to maintain agricultural output. Increasing the fertilizer use on cereals in the developing world (excluding China) by 20 percent would offer an overall net benefit in the carbon budget of between 80 and 206 10^6 t per yr^{-1}, depending on the carbon sequestration rate assumed for the re-growing forest. In those regions, where current fertilizer use is low, the relative benefits are the highest, as yield response would not yet exhibit diminishing returns. Thus, more land can be set aside without harming food security. In Sub-Saharan Africa, a 20 percent fertilizer increase, which amounts to 0.14 10^6 t of extra fertilizer, can liberate land to tie up somewhere between 8 and 19 10^6 t of CO_2 per year (average: 96 t CO_2 per 1 t fertilizer). In the Near East and North Africa, with a 20 percent increased fertilizer use of 0.4 10^6 t yr^{-1}, between 10 and 24 10^6 t of CO_2 could be sequestered on the land that is set aside (40 t CO_2 per 1 t fertilizer). In South Asia this is 22–61 10^6 t CO_2 yr^{-1}, with an annual additional input of 2.2 10^6 t of fertilizer (19 t CO_2 per 1 t fertilizer).

In summary, Vlek said that modern agricultural production world-wide is fossil fuel dependent and carbon intensive. There is a high demand for agricultural land, especially in developing countries, but the cost in CO_2 release in land conversion is substantial. The alternative is intensification, which is cheaper in CO_2 loading, but increases dependency on limited fossil fuel supplies. Sequestration of carbon on marginal land with afforestation would far outweigh the emissions associated with the production of the extra fertilizer (12 10^6 t yr^{-1}). In the long run, however, Vlek emphasized that alternative energy sources are needed to sustain agriculture.

FOOD SECURITY AND THE ENVIRONMENT: ANIMAL PROTEIN PRODUCTION IMPACTS AND TRENDS[18]

Judith L. Capper, Washington State University

Jude Capper stated that in 1800, each U.S. farm could produce only enough food to feed one other family. In the wake of considerable improvements in efficiency and productivity, each farmer currently produces, on average, enough food to feed 125 other people. However, there is a global food crisis, with the number of food-insecure people in the world increasing from 820 million in 2004–2006 to 1,020 million in 2009 (FAO, 2009b). The global population is predicted to increase to approximately 9.5 billion people by 2050. This will increase total food requirements by 70 percent compared with today (FAO, 2009a), as a function of both population size and the augmented demand for milk and meat protein resulting from more widespread global affluence. If the present competition for energy, land, and water supplies continues, Capper noted, resources available for agricultural production are likely to decrease concurrently with increased population growth. The global livestock industries, therefore, face the challenge of producing sufficient nutritious, safe, affordable animal protein to meet consumer demand, using a finite resource base.

[18] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_060826, presentation by Judith Capper (February 17, 2011).

Sustainability is defined by the U.S. Environmental Protection Agency (U.S. EPA, 2010) as “meeting society’s present needs without compromising the ability of future generations to meet their own needs.” Capper noted that popular perceptions of sustainable agriculture are often directed towards extensive low-input: low-output systems or systems that supply only the local geographic area. This is reinforced by the growing trend within the media and Internet sites of promoting an agrarian idyll of a population growing their own food in back yards or through community cooperatives. Although animal proteins are considered as staple foods in many diets, concern over the perceived environmental impact of conventional animal production may threaten social license to operate in the future.

In any agricultural or industrial sector, improving productivity allows system fixed costs to be diluted out over greater units of production, thus reducing the economic cost per unit. The same concept can be applied to environmental costs, with carbon, the fundamental unit of energy in living systems, as the currency. Capper explained that all animals require a basal daily quantity of feed nutrients to maintain vital functions and minimum activities (maintenance requirement). This can be considered to be the *fixed cost* of animal production that must be met for every animal within the population. The level of animal protein production (milk yield, growth) then determines the additional *variable costs* of the system. Nutrient energy use is a valid proxy for natural resource use (land, water, fossil fuels) and greenhouse gas emissions. Management practices that improve efficiency reduce the size of the animal population required to produce a set quantity of animal protein and thus decrease the total associated maintenance nutrient requirement, and will therefore reduce resource use and waste output per unit of food produced (Table I 3-3).

Proof of this concept is demonstrated by the improvements in efficiency seen in the U.S. dairy industry over the past 60 years. As described by Capper et al. (2009), the size of the U.S. dairy herd peaked in 1944 at 25.6 million cows, with a total milk yield of 53.0 billion kg produced through an extensive pasture-based system. By comparison, the 2007 dairy herd contained 9.2 million cows producing 84.2 billion kg of milk. The four-fold increase in milk yield per cow and consequent improvement in efficiency was facilitated by improvements in management, nutrition, and genetics. Analyzing the environmental impact of the U.S. dairy industry in 1944 compared with 2007 revealed that to produce an equivalent amount of milk, only 21 percent of the dairy population (lactating cows, dry cows, heifers, and bulls), 23 percent of the feedstuffs, 10 percent of the land, and 35 percent of the water were required, and only 24 percent of the manure was produced. Consequently, the total greenhouse gas emissions (carbon footprint) per unit of milk were reduced by 63 percent, and the carbon footprint of the entire dairy industry was 41 percent lower in 2007 compared with 1944.

Productivity has also improved substantially in the U.S. beef industry, with average beef-carcass yield per animal increasing from 274 kg in 1977 to 351 kg in 2007 (USDA, 1978; USDA/NASS, 2008). Management advances over this time period facilitated an increase in growth rate, reducing the total days from birth to slaughter and thus the total maintenance resource cost and waste output associated with beef production. Between 1977 and 2007, increasing growth rate meant that the age at slaughter was reduced from 609 days to 485 days. In combination with the increased beef yield per animal, this reduced animal numbers by 30 percent, feed use by 19 percent, water use by 14 percent, land use by 34 percent, manure production by 20percent, and the carbon footprint per unit of beef by 18 percent (Capper, 2010b).

The FAO (2006) concludes that it is essential to continue to intensify livestock production in order to maintain the efficiency gains that improve environmental sustainability. By contrast, consumers often assume that extensive, pasture-based beef systems where cattle are finished on grass are more environmentally friendly than conventional corn-based systems. It is important to note, Capper said, that between one-half and two-thirds of conventional beef animals' lives are spent on pasture and that intensive corn-based finishing only occurs in the final growth period within the feedlot. Growth rates are considerably lower in animals finished on grass, and it is difficult to achieve high slaughter weights; therefore, grass-finished cattle are usually slaughtered at around 486 kg at 679 days of age, compared with 569 kg at 453 days of age in a conventional system (Capper, 2010a). As a consequence of the reduced slaughter weight, 4.5 total animals (slaughtered animals plus the supporting population required to produce calves for rearing) are required to produce 363 kg of beef carcass in the grass-finished system compared with 2.6 total animals in the conventional system. When combined with the increased time required to grow animals to slaughter weight, this increases the carbon footprint per 363 kg of beef by 74 percent, land use by 83 percent, and water use by 326 percent (Capper, 2010a).

TABLE I 3-3 Productivity Improvements and Associated Impacts on Resource Use and Waste Management in U.S. Animal Protein Production

Protein System	Efficiency Improvement	Impacts
Dairy	Increased milk yield Increased component (fat and protein) yield	To produce an equivalent amount of animal protein from an improved system compared with an unimproved system: Smaller total animal population - Productive animals (lactating, growing) - Supporting population Reduced total maintenance requirement Reduced resource use per unit of food Reduced waste output per unit of food Reduced greenhouse gas output per unit of food
Beef	Increased slaughter weight Increased growth rate Reduced time from birth to slaughter	
Swine	Increased litter size Increased number of litters per year Reduced time from birth to slaughter	
Poultry	Reduced mortality Increased slaughter weight Reduced time from birth to slaughter	

Compared to ruminant production, swine and poultry industries are generally considered to be less environmentally threatening to climate change, because monogastric animals produce considerably less enteric methane than ruminants. Nonetheless, given the increase in poultry and swine consumption predicted to occur from now to 2050, further efficiency improvements are necessary within these industries to continue to reduce overall environmental impact. As shown in Table I 3-3, improving sow productivity (i.e., litter size, number of litters), animal growth rates, poultry mortality, and slaughter weights minimizes losses within the system, thus reducing the size of the total animal population, the resources required, and the waste output from producing a set quantity of animal protein.

The challenge of producing more animal protein to fulfill human population requirements while minimizing resource use and waste output is not confined to future scenarios, Capper explained. A recent FAO report on greenhouse gas emissions from global dairy production differentiated the results by region and demonstrated a decrease in the carbon footprint per kg of fat and protein-corrected milk at the farm gate for industrialized nations (1-2 kg CO^2-equivalent per kg milk) compared with developing areas (3-5 kg CO^2-equivalent per kg milk). When carbon footprint data are compared with the underlying data on regional milk production, a negative association is shown; that is, as milk production per cow increases, carbon footprint per unit of milk decreases. In 2007 the Chinese government announced that the human recommended daily intake of dairy products should be increased from 100 to 300 g. Given the size of the Chinese population, this would require an additional 65 million dairy animals at current daily milk yields (11 kg per day). If productivity was improved to that of the average U.S. dairy cow (29 kg per day), this would still require an increase in the dairy population, yet this increase would be confined to 23 million animals with concurrent comparative reductions in total maintenance requirements, resource use, and greenhouse gas output.

Debate continues as to the most suitable metric for assessing the sustainability of animal protein production. Various possibilities exist, including resource use per unit of food (e.g., beef, milk, cheese), acre of land or gallon of water; calories or protein output per acre; income per unit of food; labor per acre, etc. The purpose of the animal agriculture industry is to produce animal protein; therefore, it seems appropriate to use food output as a metric, yet differing regions may have environmental challenges that bring other metrics (e.g., output per unit of water in drought-stressed areas) into play. Capper noted that it is important to recognize that there is no "one-size-fits-all" management practice or system to reduce environmental impact. As the FAO (2010) report demonstrates, less-developed countries reliant on extensive production have increased greenhouse gas emissions per unit of milk, yet the economic and social value of livestock ownership is considerable. Capper emphasized that to move the global livestock industry further towards sustainability, it is necessary to consider the balance between environmental, economic, and social indexes.

The livestock industry faces a considerable challenge in producing sufficient animal protein to feed the growing population while continuing to improve sustainability. As demonstrated by improved efficiency in the U.S. livestock industry over the past 60 years, this challenge may be partially met by making productivity gains that reduce resource use and cut greenhouse gas emissions from livestock production. However, Capper noted, the metrics by which this is assessed may differ between systems, just as the management practices put into place to improve productivity will vary widely between regions. Rather than focusing on one single metric, true sustainability within the livestock industry can only be achieved by a balance between environmental impact, economic viability, and social responsibility.

GENERAL DISCUSSION

Following the presentations, participants asked for clarification on some of the information. Emmy Simmons started the discussion by asking how the farm level analyses described by Shaw and Voeste could be scaled up for use by policy makers. Greg Thoma said that this was an important issue and that the Sustainability Consortium was building a modeling infrastructure that uses linkages with other efforts, such as Field to Market, which would allow the aggregation of farm level analyses to regional or national levels. Steve Polasky suggested that it would be useful to link these farm level models to the life-cycle work being done under InVEST as well as to the spatial modeling done through HarvestChoice. Many participants voiced their support for this idea, but Thoma said that there remain challenges in doing this. For example, it is difficult to calculate water sustainability along a supply chain that includes both water stressed and nonstressed areas. Hartwig de Haen asked how the indicators being developed related to those used in the Millennium Ecosystem Assessment. This led to discussion about the need to tailor indicators to specific locations. For example, a bird index may be a useful measure of biodiversity in the United States or Europe, but probably not in many other parts of the world. Finally, it was noted that indicators related to the sustainability of livestock production were much less well developed than those for other agricultural products.

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4

THE WAY FORWARD

During the concluding session of the workshop, two breakout sessions were convened to discuss how metrics associated with sustainable food security could be improved and made more useful to policy makers. Each group was asked to identify the strengths and weaknesses of food security indicators and priorities for further research and investment as well as possible new institutional arrangements. The first breakout group examined metrics for food security, nutrition, and poverty, and the second group examined metrics related to agricultural production and natural resources. This chapter summarizes discussions during the breakout sessions as well as other ideas mentioned during workshop presentations and the background paper on metrics for food insecurity and malnutrition (see Annex A). It also includes a summary of Prabhu Pingali's suggestion to establish a peer review process to assess the methodologies used in developing these metrics.

Many participants in both groups concluded that the quality of metrics is not as good as it needs to be for accurately understanding, monitoring, or predicting food security. In particular, they stressed the importance of strengthening national level statistics both as inputs to global level indicators and more importantly for guiding and evaluating national level policies. Some participants emphasized the need for good national and local data and encouraged international funding organizations to find ways to better understand the needs of national and local decision makers. They also expressed concern about the metrics used to measure the sustainability of food production processes, given natural resource conditions, policies, and market incentives. Many participants stated that suites of metrics and 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 and at more local (including household) scales. Individuals from both breakout groups stressed the need for better spatial and temporal data; good spatial level data was seen as critical especially in targeting humanitarian aid. A number of participants suggested that an inventory of existing food security and poverty indicators be created to provide better user access and to allow users to understand the limitations of the data and methodologies used.

Some participants expressed concern about the 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 fact that indicators were often not available at the same geographic scales, they said, was particularly problematic. For example, data on production and productivity may be available at the level of households, fields, farms, landscapes, river basins, nations, regions, or continents, while data on poverty or hunger may only be available at a national or global level. Several participants emphasized the importance of collecting data, stating that information at smaller scales could also be meaningfully aggregated to meso- and macroscales.

Emmy Simmons provided highlights of the breakout session on agricultural productivity and natural resources. She noted that most of the participants believed there were relatively good data for six major categories of natural resources—habitat, soil health, water, chemicals, air quality, and greenhouse gases—but that, for the most part, little of this information was linked to economic or social variables. Several breakout session members suggested that future efforts should focus on strengthening a limited set of indicators—those most likely to have the greatest impacts, positively or negatively, on global food systems. There was also considerable support for creating a dialogue between scientists, the public and key decision-makers to assure that the science was well understood, and encouraging markets and governments to take action based on the science.

Kostas Stamoulis briefly summarized the discussion from the food security, nutrition, and poverty breakout group. He noted that most participants believed that the quality of anthropometric data are generally good, but that metrics addressing micronutrient deficiency and diet diversity are scarce and should be expanded, as they are important predictors of good nutrition. Several participants complained that information on nutritional status is generally not linked to important co-variates, such as family income or intra-household food allocation, nor are data readily available to determine whether individuals suffer from acute or chronic malnutrition, important measures for determining appropriate policy interventions.

Stamoulis described the discussion on the Food and Agriculture Organization (FAO) indicators, highlighting the need for better food balance sheets, since these are the basis for the FAO hunger indicators. Many participants emphasized the point that the FAO hunger numbers purport to provide information about food consumption, but in fact do not. They are based on 3-year trend data on aggregate food supplies or food availability, and as such, they do not reflect the changes in the number of people who are hungry because of price fluctuations or short term food supply disruptions. However, the numbers are useful as a way to focus high level attention on the problem of global hunger and to secure continued international financial support for anti-hunger initiatives.

Several participants also noted that these measures are not useful for national level decision-makers, who need to target specific anti-hunger interventions, and therefore other metrics are needed such as those developed from household survey data or other national level statistical collection efforts. Some participants suggested that household surveys, albeit costly, can provide essential national level data on key measures not covered by the FAO data or other global data sources—information on household level access and utilization of food as well as measures of malnutrition. Several participants remarked that it would be useful to have a core set of questions for household surveys that would allow for greater comparability across countries.

Also as part of the final workshop session, Prabhu Pingali of the Bill and Melinda Gates Foundation discussed the need to increase the reliability and transparency of global food security numbers and asked workshop participants to provide their views on the possibility of establishing a peer review mechanism. He explained that global numbers on hunger and poverty are important to target populations that need assistance, and indicators on natural resources and productivity help to identify the long term impact of development and to identify needed interventions. As a donor organization, the Gates Foundation uses these numbers almost on a daily basis, but the reliability and credibility of these numbers are widely questioned. Pingali noted that published worldwide hunger numbers can rise by 200 million in a matter of weeks and then fall again in a matter of weeks. Published statistics on the number of underweight children in India are increasing, but the country's economy has been growing at a rate of 8 percent a year for the last two decades. He also expressed concern that the institutions and governments generating these numbers have certain self-interest in reporting specific magnitudes and trends.

To overcome these problems Pingali suggested creating a peer review process. It could be modeled after the International Organization for Standardization, focused on certifying the quality and reliability of statistics, or an international body of experts from science academies around the world could be convened.

Workshop participants had numerous questions about the proposal, but many were supportive of the idea of having a process for the peer review of methodologies used to develop key global indicators, with some participants suggesting that a first step might be to compile an inventory of indicators and provide a platform or portal which would provide easier access to these data. Additional discussion of the proposal took place during the second workshop, and Pingali talked with the staff of the InterAcademy Council (IAC) about the possibility of managing a peer review for global statistics on food security. During the course of this project, IAC has announced that it will explore potential new peer-review mechanisms for improving the quality and reliability of statistics produced by international organizations which measure worldwide poverty, hunger, malnutrition, and general food security.

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WORKSHOP AGENDA

A SUSTAINABILITY CHALLENGE: FOOD SECURITY FOR ALL

Workshop 1:

Measuring Food Insecurity and Assessing the Sustainability of Global Food Systems

Date: February 16-17, 2011

Location: Keck Center of the National Academies
500 Fifth Street NW, Room 201, Washington, DC

OBJECTIVES:

The overarching objective of the workshop is to contribute to the global effort towards sustainable food security through the improvement of indicators used to assess and monitor progress. More specific objectives are:

- To help establish the dimensions of the sustainable food security challenge
- To review commonly used indicators from the point of view of: the data used (quality, frequency, consistency), construction of the metric/indicator and analyze methodological strengths and weaknesses
- To examine current uses and misuses of the indicators
- To identify priorities for improving existing processes and developing better data and indicators to meet the needs of users.
- To explore possible peer review mechanisms for monitoring and suggesting improvements to the metrics/indicators and promote their proper use for policies and programs.

NOTES:
The workshop will bring together a small group of experts including those responsible for key indicators of food security, key critics of those metrics, a number users and members of the Academies' committee. Participants are expected to review existing metrics, analyze plans for revision, propose directions for revision, and to consider whether or not a peer review mechanism might be useful. Background papers, briefing notes, and presentations will review and synthesize the key data and estimation problems in assessing food security and malnutrition, poverty and environmental sustainability. Members of the planning committee will prepare a workshop report.

Wednesday, February 16, 2011

8:00 AM Breakfast available

8:30 AM **Welcome and Introduction**
Per Pinstrup Andersen, Cornell University, Committee Chair

8:45 AM **Workshop Overview**
Kostas Stamoulis

MAJOR DIMENSIONS ASSOCIATED WITH SUSTAINABLE FOOD SECURITY

9:00 AM **What Do We Really Know?—Metrics for Food Insecurity and Malnutrition**
Hartwig de Haen, Former FAO Assistant Director-General, Economic and Social Development and Stephan Klasen, University of Göttingen
Numerous statistics are published reporting on world hunger and malnutrition conditions. Do we really know how many hungry people are in the world and in each country? Do we know how many under and over nourished children and adults exist worldwide and in each country? How good have the data been projecting future changes?

9:45 AM Questions for Clarification

10:00 AM BREAK

10:15 AM **Hunger and Malnutrition (Panel Discussion)**
Moderator: Marie Ruel, International Food Policy Research Institute
In this session, those knowledgeable about the construction of food consumption indices and outcome measures will present what they perceive to be their major strengths and weaknesses (including data used), plans for revision, and uses and misuses.

A. Food Consumption Indicators
- Pietro Gennari, FAO (FAO Undernourishment Indicator)
- Benjamin Senauer, University of Minnesota (FAO Undernourishment Indicator)

B. Outcome Indicators
- Lynnette Neufeld, Micronutrient Initiative (Measures of Malnutrition)
- Ricardo Uauy, London School of Hygiene and Tropical Medicine (Measures of Overnutrition / Obesity)

11:30 AM **General Discussion: How Indicators are Used and Needs of National Decision-Makers**
Moderator: Marie Ruel, International Food Policy Research Institute
- Shahla Shapouri, U.S. Department of Agriculture
- Adelheid Onyango, World Health Organization

12:15 PM LUNCH

POVERTY

1:15 PM **Measures of National and Global Poverty and Their Use in Policy Making**
Martin Ravallion, The World Bank
Presentation on measures of global poverty and food access: Advantages, shortcomings, and what should they be used for.

1:45 PM Questions for Clarification

2:00 PM **An Alternative Poverty Indicator**
James Foster, The George Washington University (Oxford Poverty and Human Development Initiative)

2:15 PM **Panel Discussion** (Martin Ravallion, James Foster and Stephan Klasen)
Moderator: Marco Ferroni, The Syngenta Foundation for Sustainable Agriculture
Panel will focus on the way forward for the measurement of poverty and inequality and how to assure that measures are useful for policy makers.

2:30 PM **General Discussion on Indicators for Hunger, Malnutrition, and Poverty**
Moderator: Marco Ferroni, The Syngenta Foundation for Sustainable Agriculture

- How important are global numbers for hunger, malnutrion and poverty? For whom?
- Do measures of poverty, food security, and malnutrition move in the same direction? If not why not? Is this a problem with the measures or does it highlight more complex issues?
- Are numbers comparable between countries and overtime?
- What information do decision-makers really need and for what?

3:15 PM BREAK

NATURAL RESOURCES AND AGRICULTURAL PRODUCTIVITY

3:30 PM **Introductory Comments: Natural Resources and Agricultural Productivity**
Emmy Simmons, U.S. Agency for International Development (ret.)

3:45 PM **A. Measuring Productivity and Natural Assets (Panel Discussion 1)**
Moderator: Philip Pardey, University of Minnesota
Panel will examines measures of agricultural productivity and natural resource use with regard to sustainable food security.

- Richard Perrin, University of Nebraska-Lincoln (Measures and Meaning of Agricultural Productivity)
- Stanley Wood, IFPRI (Expanding Agricultural Productivity Measures and Linking to Eco-System Services--A Spatially Explicit Approach)

- Steve Polasky, University of Minnesota (Measuring and Valuing Natural Assets)
- Peter McCornick, Duke University (Water, Agricultural Productivity and Environmental/Health Services)

4:45 PM **General Discussion on Measuring Productivity and Natural Assets**
Moderator: Philip Pardey, University of Minnesota

5:00 PM ADJOURN

6:00 PM **Working Dinner for Steering Committee and Invited Guests**
Brief Remarks: Emmy Simmons, U.S. Agency for International Development (ret.)
Acadiana Restaurant Lake Room, 901 New York Avenue NW Washington, DC

Thursday, February 17, 2011

8:00 AM Breakfast available

8:30 AM **Review of Day One and Welcome to Day Two**
Per Pinstrup Andersen, Cornell University, Committee Chair

8:45 AM **B. Composite Indicators for Sustainable Production (Panel Discussion 2)**
Moderator: Jennifer Shaw, Syngenta
Panel will look at composite indicators for sustainable production and natural resource use and how they can be used practically to promote sustainable practices and inform consumers and policy maker.

- Greg Thoma, University of Arkansas – The Sustainability Consortium work (Overview of Metrics and Indicators, Different Approaches, Strengths and Weaknesses)
- Jennifer Shaw, Syngenta (Industry Perspective on Use of Metrics)
- Dirk Voeste, BASF (Experience on Gathering Meaningful Data for Life Cycle Analyses)

9:45 AM BREAK

10:00 AM **C. Food Security and the Environment (Panel Discussion 3)**
Moderator: Jason Clay, The World Wildlife Fund,
"Feeding 9 Billion and Maintaining the Planet"
Panel will discuss plausible trajectories for sustainably increasing food supplies and identify data that are available and needed to understand possibilities and trade-offs.

- Jon Foley, University of Minnesota (Food Security and Land Cropping Potential)
- Paul Vlek, University of Bonn (Contribution of Agriculture to Climate Change and Potential for Mitigating the Effects of Climate Change) (videoconference)
- Jude Capper, Washington State University (Animal Protein Production Impacts and Trends) (teleconference)

11:00 AM **General Discussion on Indicators for Natural Resources and Agricultural Productivity**
Moderator: Jason Clay, The World Wildlife Fund

11:30 AM LUNCH

THE WAY FORWARD

12:30 PM **A Proposal**
Prabhu Pingali, The Bill & Melinda Gates Foundation (videoconference)

12:45 PM **Breakout Discussions: The Way Forward**
Group 1: Hunger and Malnutrition, Poverty (Kostas Stamoulis, Keck 201)
Group 2: Natural Resources and Agricultural Productivity (Phil Pardey, Keck 207)
Each breakout group of participants will be asked to answer the set of questions based on their expertise and information presented during the workshop's earlier sessions. Additional questions specific to the topic may be added later.

- Meeting the challenge—providing the right data and information and the right institutional and organizational system.
- How can existing and new data collection efforts be developed to efficiently provide needed information?
- What additional research is needed to inform processes and to develop more appropriate indicators?
- What institutional arrangements are needed?

1:30 PM **Feedback from Breakout Groups**
Per Pinstrup Andersen, Cornell University, Committee Chair

2:00 PM **General Discussion – Key Recommendations**
Per Pinstrup Andersen, Cornell University, Committee Chair

2:45 PM **Wrap Up and Summary**
Per Pinstrup Andersen, Cornell University, Committee Chair

3:00 PM ADJOURN for Public Session

WORKSHOP PARTICIPANTS

Per Pinstrup-Andersen (Chair)
Cornell University

Richard Bissell
National Academy of Sciences

Jude Capper (Teleconference)
Washington State University

Gero Carletto
The World Bank

Jason Clay
World Wildlife Fund

Hartwig de Haen
University of Göttingen

Bert Drake
Smithsonian Environmental Research Center (retired)

Marco Ferroni
Syngenta Foundation for Sustainable Agriculture

Jon Foley
University of the Minnesota

James Foster
The George Washington University

Lars Friberg
Embassy of Sweden

Pietro Gennari
Food and Agriculture Organization of the United Nations

Matt Haggerty
National Academy of Sciences

Yurie Tanimichi Hoberg
The World Bank

Diana Jerkins
U.S. Department of Agriculture

William Jury (NAS)
University of California, Riverside

Emi Kameyama
National Academy of Sciences

Stephan Klasen
University of Göttingen

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Hiram Larew
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Stewart Leeth
Smithfield Foods

Peter McCornick
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Linda Meyers
Institute of Medicine

Marina Moses
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Lynnette Neufeld
Micronutrient Initiative

Adelheid Werimo Onyango
World Health Organization

Philip Pardey
University of Minnesota

Ricardo Perrin
University of Nebraska-Lincoln

Prabhu Pingali (NAS) (Videoconference)
Bill and Melinda Gates Foundation

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Paul Vlek (Videoconference)
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Dirk Voeste
BASF Crop Protection

Aaron Williams
U.S. Agency for International Development

StanleyWood
International Food Policy Research Institute

SPEAKER BIOGRAPHICAL INFORMATION

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.

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.

JON FOLEY is the Director of the Institute on the Environment (IonE) at the University of the Minnesota, where he also holds a McKnight Presidential Chair in the Department of Ecology, Evolution and Behavior. Dr. Foley's work focuses on the behavior of complex global environmental systems and their interactions with human societies. In particular, Foley's research group uses state-of-the-art computer models and satellite measurements to analyze changes in land use, ecosystems, climate and freshwater resources across regional and global scales. Foley joined the University of Minnesota in 2008, after spending 15 years on the faculty of the University of Wisconsin. He has won numerous awards and honors, including the National Science Foundation's Faculty Early Career Development Award, the Samuel C. Johnson

Distinguished Faculty Fellowship, the J.S. McDonnell Foundation's 21st Century Science Award, and the Sustainability Science Award from the Ecological Society of America. In 1997, President Bill Clinton awarded him the Presidential Early Career Award for Scientists and Engineers. He has also been named an Aldo Leopold Leadership Fellow.

JAMES FOSTER is Professor of Economics and International Affairs at The Elliott School of International Affairs at The George Washington University. Professor Foster received his Ph.D. in economics from Cornell University where he received the Selma Fine Goldsmith Award for his dissertation. He held positions at the Krannert School of Management at Purdue University and Department of Economics at Vanderbilt before joining the Elliott School. He received the Unilever Fellowship (UK) and the Robert Wood Johnson Investigator Award in Health Policy, and holds a Doctorate Honoris Causa, from Universidad Autonoma del Estado de Hidalgo (Mexico). Professor Foster's research focuses on welfare economics — using economic tools to evaluate the well-being of people. His joint 1984 Econometrica paper is one of the most cited papers on poverty; it introduced the FGT Index, which has been used in thousands of studies and was the basis for targeting the Progresa/Oportunidades program in Mexico. Other work includes a book project on economic inequality with Nobel Laureate Amartya Sen; a paper on poverty and growth in a recent issue of the International Economic Review with Miguel Szekely, Undersecretary of Education in Mexico; and a paper measuring multidimensional poverty with Sabina Alkire, Director of Oxford's Poverty and Human Development Initiative.

PIETRO GENNARI is the Director of the *Food and Agriculture Organization* of the United Nations (FAO) Statistics Division since the beginning of 2009. He has over 25 years of experience in the main areas of official statistics and in managing statistical programmes, both at the national and international level. He began his professional career in 1986 working in the National Planning Commission for the System of Wholesale Food Markets, and subsequently served for five years as Senior Statistician at the Institute for Studies and Economic Analyses (ISAE), a public research Institute that conducts analyses and forecasts in support of the economic policy decisions of the Italian government. Between 1993 and 2003, he worked for the Italian National Institute of Statistics, first as Head of the Labour Force Survey Division and then in the Directorate for Short-Term Business Statistics. From August 2003 to November 2005, Mr. Gennari was Adviser on Economic Statistics for the UN Regional Commission for Asia and the Pacific (ESCAP), assisting the National Statistics Offices of the Region in improving basic data sources for the compilation of the main economic indicators. At the end of 2005 he became the Director of ESCAP Statistics Division, where he launched a new programme of statistical capacity building and redesigned the statistical dissemination strategy.

STEPHAN KLASEN is professor of development economics and empirical economic research at the University of Göttingen, where he also heads the Ibero-American Institute. Previously he was professor of economics at the University of Munich as well as a fellow at King's College in Cambridge and an economist at the World Bank in South Africa. His research interests are in population, labor, welfare, and development economics. He holds a BA, MA, and Ph.D. from Harvard University. His current research interests include an assessment of the relation between labor market events and demographic decisions at the household level, an analysis of the determinants of undernutrition and child mortality in developing countries, the linkages between inequality, growth, and well-being, and the causes and consequences of gender inequality in developing countries.

PETER McCORNICK is the Director of Water Policy at Duke University's Nicholas Institute. In this capacity he focuses on critical water resources management issues, with on-going activities in North East Africa, South East Asia, South Asia, the Middle East, and the US. He has approximately three decades of experience in addressing the challenges in the water resources, agriculture and environment sectors, that has included research, policy development, planning, implementation, teaching and capacity building. Prior to joining Duke in 2008, Dr. McCornick was the Director for Asia for the International Water Management Institute. Previously he was assigned as water resources and irrigation specialist to the water and coastal resources team of the United States Agency for International Development (USAID). In addition, he has advised and provided input to a number of other bilateral, multi-lateral and private entities including the World Bank, the Asian Development Bank, the World Health Organization, the State Department and the United States. He has a PhD and MS in water resources and irrigation engineering from Colorado State University, and a BSc in agricultural engineering from the University of Newcastle upon Tyne in the UK. He is a registered Civil Engineer in Colorado, and a member of the American Academy of Water Resources Engineers (AAWRE).

LYNNETTE NEUFELD is a technical expert in international nutrition and has 25 years of experience researching diverse nutritional and health-related issues that affect the world's most vulnerable populations. As Chief Technical Advisor at the Micronutrient Initiative (MI), Dr. Neufeld helps maintain the integrity of the organization's programs by providing technical support to ensure up-to-date evidence-based design and strong monitoring for program improvement. She also contributes to the generation of new evidence by active maintenance of a research portfolio related to many aspects of nutrition and micronutrients, using diverse methodologies from surveys and other observational methods to randomized controlled trials and rigorous program effectiveness evaluations. Her areas of expertise include: nutritional factors affecting fetal and early childhood growth and development, causes, consequences and strategies to control anaemia and micronutrient malnutrition during pregnancy and early childhood and women's nutritional status during pregnancy. Dr. Neufeld received her Ph.D. and M.Sc. in International Nutrition from the Cornell University.

ADELHEID ONYANGO is a technical officer in the Department of Nutrition for Health and Development at the World Health Organization (WHO), Geneva. Dr. Onyango is a key member of team that developed the WHO child growth standards and associated application tools. Her functions include planning and managerial oversight for global and regional level capacity building for the implementation of growth standards; country-level advocacy for appropriate policies and technical support for integration of the WHO growth assessment tools into national child health programs and the establishment/maintenance of nutrition surveillance systems. Dr. Onyango holds a Master's degree and Ph.D. in Nutrition, both from McGill University, Canada.

RICHARD PERRIN is the Jim Roberts Professor of Agricultural Economics at University of Nebraska-Lincoln. Dr. Perrin is an agricultural economist who specializes in the economics of ethanol production. His recent work has focused on biofuel economics, including the environmental impacts of corn ethanol, the potential of switchgrass for cellulosic ethanol and the potential for crop residues as energy crops. His recent findings have been published in the Proceedings of the National Academy of Sciences; Energy Policy; Biofuels, Bioproducts and Biorefining; and BioEnergy Research. He also has studied the relationship between grain ethanol production and food prices, both in the United States and in food-insecure areas of the world. He has a long history of examining agricultural productivity issues in the developing world. Before joining the University of Nebraska-Lincoln in 1993, Perrin was a faculty member at North Carolina State University and Iowa State University and was an economist for the International Maize and Wheat Improvement Center (CIMMYT) in Mexico. He has a doctorate in agricultural economics and a bachelor's degree in agricultural business from Iowa State University.

STEPHEN POLASKY (NAS) is a Fesler Lampert Professor of Ecological/Environmental Economics and an interdisciplinary chair in the Departments of Applied Economics and Ecology, Evolution and Behavior, University of Minnesota. He joined the University of Minnesota in 1999 after serving professor positions at Boston College and Oregon State University. Dr. Polasky's research interests include ecosystem services; natural capital; biodiversity conservation; endangered species policy; integrating ecological and economic analysis; renewable energy; environmental regulation; and common property resources. As an Institute on the Environment resident fellow, he is working to expand current integrated models showing the impact of land use on ecosystem services. In addition, he seeks to engage public and private sector groups to improve land use planning. He holds a Ph.D. from University of Michigan.

MARTIN RAVALLION is Director of the Development Research Group of the World Bank. He has held various positions in the Bank, since he joined as an Economist in 1988. He holds a Ph.D. in economics from the London School of Economics, and has taught economics at L.S.E., Oxford University, the Australian National University, and Princeton University. His main research interests over the past 25 years have concerned poverty and policies for fighting it. He has advised numerous governments and international agencies on this topic, and he has written extensively on this and other subjects in economics, including three books and over 180 papers in scholarly journals and edited volumes. He currently serves on the Editorial Boards of ten economics journals, is a Senior Fellow of the Bureau for Research in Economic Analysis of Development and a Founding Council Member of the Society for the Study of Economic Inequality.

BENJAMIN SENAUER is a Professor in the Department of Applied Economics at the University of Minnesota. He served as Director of the Center for International Food and Agricultural Policy at the University from 1993-1999 and served as Co-Director of The Food Industry Center from 2001-2007. He received his Ph.D. in 1974 from Stanford University. During 1984-1985 and again in 1999-2000, he was a visiting research fellow at the International Food Policy Research Institute. He was a visiting scholar at Cambridge University in Spring

1990, at the World Health Organization in Spring 1998, and the Food and Agriculture Organization of the United Nations in 2004. His primary areas of expertise are consumer behavior, food marketing, household economics, and food and nutrition policy. He has taught courses in consumption economics, food marketing, microeconomic theory, world food problems, and agricultural development. He has co-authored two influential books: *Food Trends and the Changing Consumer and Ending Hunger in Our Lifetime: Food Security and Globalization*, which received the Agricultural & Applied Economics Association (AAEA) Quality of Communication Award.

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ANNEX A

WHAT DO WE REALLY KNOW?

METRICS FOR FOOD INSECURITY AND MALNUTRITION

Hartwig de Haen, Stephan Klasen and Matin Qaim[1]

Paper presented at the workshop on Measuring Food Insecurity and Assessing the Sustainability of Global Food Systems, February 16-17, 2011, Keck Center of the National Academies, Washington, DC.

1. INTRODUCTION

Recently, the International Food Policy Research Institute (IFPRI) published an estimate of hunger in 12 sub-Saharan African countries. Based on an analysis of household surveys the authors found that in the late 1990s 59 percent of the population was food energy deficient (Smith et al., 2006). This result was in stark contrast to estimates by the Food and Agriculture Organization of the United Nations (FAO), based on food balance sheets for the same countries, the same period and using the same criterion of energy deficiency as an indicator of undernourishment. The FAO prevalence estimate was 39 percent (Smith et. al., 2006, p 45), hence significantly lower. Not only did the two methods differ with respect to the mean level of undernourishment, the ranking of the 12 countries differed as well. In other words, there is not even a close correlation between the two estimates. This example of divergent estimates of hunger, measured with the same criterion, namely food energy deficiency, suffices to raise interest in a thorough comparative assessment of the various methods used to estimate hunger.

Numerous statistics are published reporting on the food security and nutrition situation at global, country, household and individual levels. A comprehensive overview of available or conceivable indicators can be found under the FAO-led Food Insecurity and Vulnerability Information and Mapping Systems initiative, FIVIMS, (http://www.fivims.org). FIVIMS was established, initially as an inter-agency initiative following the World Food Summit (WFS) in

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1996, which determined that *food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life* (WFS Plan of Action, 1996). This widely accepted definition underlines the multidimensional nature of food security, comprising level and stability of food access and availability, adequacy of food use and food consumption and nutritional status. Conversely, it explains that food insecurity, i.e. the absence of food security, can be the result of very diverse factors.

The equally broad and overlapping concept of nutrition security determined by dimensions of food, care and health, can be assessed through a number indicators, including those measuring undernutrition as well as overnutrition. Per Pinstrup-Andersen talks about the triple burden of malnutrition, differentiating between (i) food energy deficiency, (ii) deficiency in specific nutrients, especially micronutrients, which are also key for an active and healthy life, and (iii) excessive net energy intake leading to overweight and obesity (Pinstrup-Andersen, 2007). In view of this multi-facetted character of food insecurity and malnutrition, it is not surprising that—when indicators measure different dimensions—the conclusions may also be different from one indicator to another. However, where different methods are used to measure the same phenomenon, one would expect only little, if any differences. The comparative assessment provided in this paper intends to discuss the reasons for differences between methods and indicators in more detail. While we recognize that the obesity problem is increasing, including in developing countries, we concentrate primarily on measures of food deprivation and undernutrition.

Obviously, before a specific food insecurity information and mapping system is set up, clarification is needed, as to which aspect of food insecurity is to be measured in each particular situation and by which indicator. Expressed in simple terms, people are deemed food insecure when their consumption of food is insufficient, insecure and/or unsustainable (Maxwell and Frankenberger, 1995). They live in hunger or fear of starvation. Although hunger is commonly understood as a sensation of not having enough to eat, its definition and measurement are not at all trivial. On the one hand, the extent of hunger can be measured as a lack of essential nutrients in the diet. A widely used indicator for this is food energy deficiency. On the other hand, hunger may also be the result of humans' inability to absorb and use food energy and specific nutrients for body functions, implying that the overall nutritional status may also be affected by people's health. Accordingly, the combined effects of access to food and of food absorption and use are best measured through outcome indicators that inform about people's actual nutrition status such as undernutrition or overnutrition.

Before proceeding to discuss the advantages and disadvantages of these various approaches to the topic, it is necessary to clarify the purpose of measurement. Two quite different purposes can be distinguished. One is to be informed about the extent and consequences of an actual food emergency caused by a sudden drop in supply or access to food. In such situations, indicators must provide information about people's immediate needs of essential nutrients to ensure survival. Indicators must be easy and quick to measure and useful for the design of humanitarian aid action. The second purpose relates to chronic food insecurity, caused by long term food deprivation linked to structural poverty and poor nutrition. One such indicator is "undernourishment", a measure of 'chronic food insecurity, in which food intake is insufficient to meet basic energy requirements on a continuing basis' (FAO, (SOFI, 1999), p. 11). Information about chronic food insecurity is needed for an assessment of level, geographical distribution and trends of hunger and/or for the design and implementation of anti-hunger policies, strategies and investment that seek to reverse undesirable trends. This paper focuses on indicators of chronic food insecurity.

To be useful for a comprehensive assessment, indicators of food insecurity should provide answers to at least three questions, namely: Who are the food-insecure? How many are they? And where do they live? If the purpose of the measurement goes beyond assessment and includes the design of policy responses, the indicators should also help answering the more ambitious question: Why are people food insecure, what are the underlying causes and hence, what should be done?

Numerous methods are in use to measure certain aspects of food insecurity. They can be summarized as follows:

1. Indicators derived from food balance sheets
2. indicators based on household consumption surveys
3. indicators derived from anthropometric measurements
4. indicators derived from medical assessments
5. Composite indicators.

Methods (1) to (3) currently represent the principal tool kit. Both the first and the second compare levels of nutrient consumption with levels of nutrient requirements. While both use science-based nutritional norms as requirement standards, they differ in the source of information about people's food consumption. The first, used by FAO, calculates food available for human consumption from national food balance sheets (FBS) and uses different information sources for a statistical measure of dispersion to approximate the distribution of food consumption levels within countries. The second derives the estimates of mean as well as dispersion of food consumption from household surveys, asking respondents to recall food consumption during a reference period. The third method relies on physical measurements of people (principally weight and height measurement, often concentrating on children) as indications of their nutritional status.

The fourth method provides additional data from medical analysis. This can include clinical assessments, such as the observation of physical signs on the body that are symptomatic of nutritional disorders (e.g., loss of skin pigment, edema) or biochemical assessment through the examination of blood or urine. At the population level, health indicators such as child mortality or low birth weight are also sometimes used as proxies for nutritional status. Finally, a number of efforts have been undertaken recently to combine specific indicators into composite indicators seeking to capture several critical dimensions of food insecurity and malnutrition at the same time. The Global Hunger Index published jointly by IFPRI and the German Welthungerhilfe is such an example designed for cross-country comparison. While they do not as such generate additional measurements, composite indicators aim to facilitate communication of the comprehensive nature of food insecurity and malnutrition.

To date, a consensus among experts on the reasons for discrepancies between the results obtained from different methods is still elusive. The mentioned case of contradicting estimates of undernourishment in countries of Sub-Sahara-Africa is one such example. The apparent contradictions between only moderate estimates for the prevalence of undernourishment in the overall population of India versus the much higher rates of undernutrition among India's children that result from anthropometric measurements are another example (see below). It is hoped that the following discussion, which particularly examines the first three of the mentioned methods in detail, will contribute to some progress towards a consensus regarding the most realistic measurements.

We critically review the three principal methods with regard to their measurement approach, the accuracy of the underlying data, and their usefulness for policy decisions, including projections and the simulation of nutritional impacts of shocks. The intention is not to describe the real food security situation but rather to describe and compare methods and indicators and make some suggestions for improvement and future research.

As part of a focus on sustainable global food security, the National Research Council's Roundtable on Science and Technology for Sustainability is planning a workshop to examine these indicators, reviewing the approaches used in developing the indicators and assessing their strengths and weaknesses. This paper is a background paper for this workshop.

2. THE FAO INDICATOR OF UNDERNOURISHMENT

Definitions, Assumptions and Main Sources of Empirical Evidence

FAO estimates the prevalence of undernourishment, expressed as the share of people in a national population not meeting their minimum food energy requirements. It is assumed that food energy deficiency is the most critical indicator of hunger. The method is based on three key parameters: the mean quantity of calories available for human consumption per person, the rate of inequality in access to those calories within the population and the minimum amount of kilocalories required by that population on average, based on the gender and age structure.

The graph in Figure I A-1 illustrates the methodological procedure for estimating the proportion of the population whose food energy availability is below requirement, i.e., who are undernourished. The function f(x) depicts the proportion of the population corresponding to different dietary energy consumption levels (x), μ_x the mean dietary energy intake per person and r_l the minimum acceptable dietary energy requirement (MDER). The area under the curve left of r_l represents the proportion of the population not reaching the minimum level of dietary energy requirement, i.e. the prevalence of undernourishment, p_U. Multiplied with the size of the population for the respective period it gives the number of undernourished.

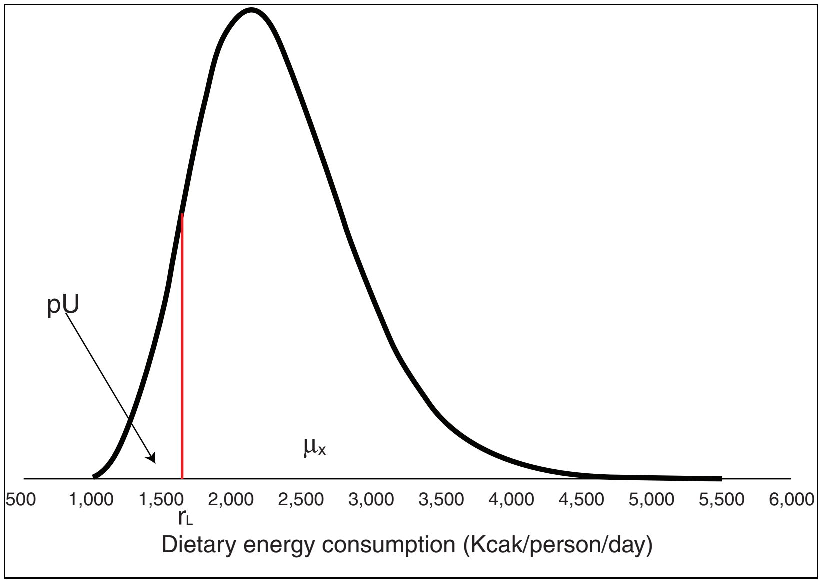

FIGURE I A-1: The FAO method of estimating undernourishment
NOTE: Distribution of dietary energy consumption

The amount of food available for human consumption is calculated from national FBS, compiled as the balancing item after considering production, trade, stock changes, non-food uses and extra-household waste. The per capita Dietary Energy Supply (DES) is obtained by aggregating all food items, converting the quantities into energy values and dividing the aggregate volume by the total population. It is noted that the indicator measures food available for human consumption at the household level, and not actual food intake. However, FAO considers it to be a close enough approximation of actual dietary energy consumption.

The inequality of access to food is estimated assuming a log-normal distribution function (Figure I A-1). This function with its short lower and longer upper tail was chosen because it reflects 'the fact that wastages, food fed to pets etc. are likely to be confined to the upper tail representing the richer and more affluent households' (FAO, 2003, p.12). The function is defined by the mean level of dietary energy consumption per person and the Coefficient of Variation (CV). The mean is assumed to equal the DES from the FBS. The CV is derived from the sample distribution of kilocalorie consumption per person as measured from available household surveys. Where food consumption information is not directly available from household surveys, survey data on food expenditure or income are used to derive estimates of dispersion. Where no survey data are available at all, data from comparable neighboring countries are used.

The third principal parameter needed for the FAO method is the aggregated Minimum Dietary Energy Requirement per person (MDER). This is the amount of food energy needed to balance energy expenditure in order to maintain an acceptable minimum body-weight, body composition and a level of minimum ('sedentary') physical activity, consistent with long-term good health. This includes the energy needs for optimal development of children, deposition of tissues during pregnancy and secretion of milk during lactation consistent with the good health of mother and child. The recommended level of dietary energy consumption for the average of a population is the mean energy requirement of the healthy, well-nourished individuals who constitute that population.[2]

Who Uses the FAO Indicator and for What?

FAO has been publishing estimates of undernourishment in irregular intervals in its World Food Surveys since the 1960s. While scope and contents have been kept broadly similar, the country coverage as well as details of the methodology have been gradually adjusted over the years. Since 1999, the indicator is being published annually as a three-year average in the flagship publication 'The State of Food Insecurity in the World' (SOFI). Beginning with the 2009 edition, SOFI is published jointly by FAO and the World Food Program (WFP).

According to the latest edition (SOFI, 2010), covering the period 2005-2007, the total number of undernourished worldwide was estimated at 847 million people, of whom 835 million were living in developing countries. The number has hardly changed since 1990-1992 (the base year for the WFS goal and of the hunger target of the first Millennium Development Goal (MDG-1) aimed at halving, respectively, the number and the percentage of undernourished by 2015. On the other hand, the prevalence of undernourishment declined from 16 to 13 percent worldwide and from 20 to 16 percent in the developing countries. Since 2008, FAO has also published a preliminary estimate of undernourishment for the respective current year, using a simplified ex-post projection (see below). According to this method, the number of undernourishment was estimated at 925 million in 2010, down from 1,02 billion that had been estimated for 2009 using the same ex-post projection method (SOFI, 2009).

The main purpose of publishing the indicator regularly for a very large number of countries is to inform the global community about levels and trends of undernourishment (chronic hunger) in the world and thus facilitate global and regional governance of food security, while also advocating for stepped up efforts in hunger reduction. The indicator measures chronic food insecurity at national levels. It does not inform about the actual distribution of the number of hungry within countries nor is it the intention to provide actionable information for policy responses at sub-national levels. The estimates are therefore primarily of interest for international comparisons and for assessments of changes over time.

The publication is receiving wide attention by the media and the wider public and clearly fulfills its purpose to advocate action against hunger. The indicator is also used by food security analysts. FAO and its governing bodies, in particular the Committee on World Food Security (CFS) as well as many other international and national organizations concerned with development cooperation, refer to the estimates regularly. Presumably, various donors use the indicator also as one key information source for the ranking of priorities for aid allocations. The FAO Undernourishment estimates also serve as one of the two official indicators of progress towards target 2 of Millennium Development Goal One ("Halve, between 1990 and 2015, the proportion of people who suffer from hunger"). The other indicator is 'Prevalence of underweight children under five years of age' using anthropometric assessments (see below).

[2] The norms have been defined by the FAO/WHO/UNU Expert Consultation on Human Energy Requirements in 2001, which established energy standards, published in 2004, for different sex and age groups performing sedentary physical activity and with a minimum acceptable body-weight for attained heights.

Since a number of years, IFPRI has used the FAO estimates of the prevalence of undernourishment as one of three equally weighted indicators to construct its Global Hunger Index (GHI), with the other two being the prevalence of underweight in children under the age of five and the mortality rate of children under five years of age.

Governments of developing countries do take note of FAO's undernourishment estimates as an indicator of the extent of hunger and of progress or retreat over time. Severe levels of undernourishment in any one country provide justification for appropriate policy measures to be put in place to remedy the situation. However, the indicator does not, and is not meant to, provide directly actionable information for policy design at sub-national level,

Sources of Funding – Past and Future

As informing the world about the scale, geographical distribution and implications of food insecurity belongs to the core functions of FAO, work in basic statistics as well as the preparation of the undernourishment indicator and its publication are normally funded from FAO's core budget. However, funding of FAO's statistics program has been rather tight for a number of years. The problem was recognized and a reform project launched, but its implementation is still ongoing. This may have critical implications for the quality of the data base and for the expert capacity in FAO to conduct the compilation of the undernourishment indicator.

Strengths and Weaknesses of the FAO Indicator

Undoubtedly, the main strength of the FAO method is its world-wide coverage with estimates for more than 100 countries, which enables the monitoring of national trends and tracking of progress and setbacks using the same methodology and criteria for all. The main weakness is the fact that it relies on national statistics compiled in FBS for the estimation of the dietary energy supply, so that the accuracy of the method depends critically on the quality of the statistical data obtained from member states and stored in FAOSTAT following a quality check. One can therefore not rule out that both levels of undernourishment between countries as well as changes in the indicator from one year to another within a country are determined by erroneous data rather than a real change in the number of undernourished. The short (yearly) intervals between publications of the indicator make such 'over-interpretation' more likely. Various authors have also criticized methodological issues, including the focus on food energy, the compilation of the dispersion of the intra-national distribution of food consumption and the standards used for calculation of minimum dietary requirements. In the following, some of these points will be discussed in more detail.

Mean Dietary Energy Supply per Person (DES)

FAO compiles the DES from FBS and uses it as an indicator of food energy consumption. The quantities of food commodities available for human consumption are calculated after deducting the net exports, stock increase, non-food use and extra-household waste from domestic production. This raises several questions. The first is whether food energy deficiency is an adequate indicator of food insecurity; the second is whether dietary energy supply is a good approximation of food energy intake; the third concerns the accuracy of the FAOSTAT data base.

(1) Is average food energy deficiency an adequate indicator of food insecurity? Obviously, an adequate, healthy diet must satisfy human needs for energy and all essential nutrients. In fact, according to the Report of a Joint FAO/WHO/UNU Expert Consultation on Human energy requirements (FAO, 2001) "dietary energy needs and recommendations cannot be considered in isolation of other nutrients in the diet, as the lack of one will influence the others." Adequate intake of food energy is essential for the metabolic and physiological functions of humans, and in this sense FAO focuses on the key indicator. However, as very often other nutrients are lacking in the diet, in particular micronutrients such as iron, vitamin A and zinc, comprehensive assessments of people's nutritional status should ideally not be limited to the food energy deficiency indicator. In principle, the food balance sheet data can also be used to assess the level of micronutrient consumption and adequacy (Wuehler et al., 2005), but the level of commodity group aggregation is relatively high, which is a drawback that weighs more heavily for micronutrients than for calories. The use of three year averages generates other uncertainties. In a country where the fluctuations within the three years are very large, food insecurity is arguably a much more serious problem than in a country where the three year average is the same but caloric availability is much more stable.

(2)Is dietary energy supply a good approximation of dietary energy intake? As the dietary energy supply includes foods, which are subsequently lost or wasted at the retail and household levels, the method by definition overestimates the actual food energy intake.

(3) How accurate are the FAO food balance sheet data? FAO has been criticized by various authors for a lack of accuracy of the data inputs used to calculate the mean per caput DES. Svedberg suggests that "food availability is underestimated (by FAO) in most parts of the developing world, although less so elsewhere than in Africa" (Svedberg, 2002). He suggests that often the substantial share of food produced for subsistence tends to be underestimated in official statistics, leading to an overestimation of undernourishment. Deviations from FAO's estimates have also been found in the IFPRI study of 12 African countries mentioned in the Introduction, although in this case, the critique is that FAO's measure *underestimates* hunger.

Testing the validity of these claims is not easy. Conceptually, the FAO method does capture all components of supply and utilization, including subsistence production; however the estimates are obviously subject to possible errors. In particular, assumptions regarding post-harvest losses are often not transparent and there is very little hard data available on its level (let alone its country-by-country distribution and trends over time). Moreover, it must be noted that, although the FAO Statistics Division has to fill in missing data, in particular for stock changes, non-food use and wastage, or use data from other sources, e.g., on trade, a major part of the data input originates directly from countries. The case of India is worth mentioning here, as FAO's estimates of rising numbers of undernourished in spite of the country's strong economic growth are rather surprising. Whereas one would assume that economic growth in recent years should have increased per capita food consumption significantly, the statistics used to estimate undernourishment do not confirm this. FBS data show India's per caput consumption stagnating around 2300 kcal/person/day between 1999/01 and 2005/07. India's own surveys even show a steady decline of per caput consumption during this period (Chattapadhyay and Chowdhury, 2010). A thorough analysis to explain this paradox is urgent, also because the development in India is of great significance for global trends (see also Deaton and Drèze, 2008; SOFI, 2008; and discussion below).

Inequality of Food Energy Consumption at National Level

FAO's approach to compile the coefficient of variation (CV) of the intra-national distribution of dietary energy supply has been subject to intensive debate among experts. The debate has been centering around two questions, one regarding the realism of the CV estimate, the other regarding the assumptions for changes of the distribution over time.

Is the CV parameter realistic? The critical arguments raised by experts are not all consistent and partly contradictory. Svedberg suggests, for example, that "FAO must have overestimated the variance in the calorie-availability distribution across households, because the ensuing habitual intakes in the lower tail are impossibly low for living households" (Svedberg, 2003, p. 25). The mentioned IFPRI study of 12 African countries comes to the opposite conclusion. Based on household expenditure surveys, Smith et al. (2006) estimate an average CV of energy availability of 0.62 for the 12 African countries, whereas the FAO estimate for the same countries is 0.3, hence much lower. Other household surveys result in similar high dispersion parameters for food intake (Ecker et al., 2010).

FAO itself recognizes that the coefficient cannot be completely specified even without considering problems associated with survey practices, measurement errors and sample design (FAO, 2003, p. 23) The reason given relates to the (realistic) hypothesis that people's food consumption is not only influenced by income, but also by their age/sex specific energy requirement. The following formula is used to calculate the CV:

$$CV(x) = \sqrt{CV^2(x|v) + CV^2(x|r)}$$

where CV(x) is the total CV of the household per capita dietary energy consumption, CV(x |v) is the component due to household per capita income (v), and CV(x |r) is the component due to other sources of variation, in particular energy requirement (r). CV(x |r) is considered to be a fixed component and is estimated to correspond to about 0.20. CV(x |v) is, however, estimated on the basis of household survey data (FAO, 2003, p. 38).

According to FAO, the CV resulting from the analysis of survey data using the formula above is occasionally further corrected to remove components of variation that are considered not plausible. Moreover, as the log-normal distribution would not exclude energy intake levels below the absolute minimum for survival or above possible maximum food intake levels, lower and upper bounds for the range of the CV have been set at 0.2 and 0.35.[3] The IFPRI study suggests that due to these adjustments the FAO CVs may be biased downward (Smith et al. 2006, p. 50). However the empirical evidence for such a conclusion is limited.

Is it realistic to assume no change of the CV over time? FAO has so far kept most CVs constant over time. Adjustments of the CVs have been limited to a few cases. FAO justifies this by a lack of available survey data, but suggests also that "there has been little, if any, change in the inequality of income/expenditure in most countries" (FAO, 2003, p. 16). The implications of this procedure for the estimates of undernourishment could indeed be significant. Firstly, empirical evidence suggests that, especially since the 1990s when structural adjustment programs began to take effect in more developing countries, income distributions do change as economies grow. In fact, there is evidence that income and expenditure inequality in a majority of developing countries increased (at least slightly) between the early 1980s and the mid 1990s; since then trends are more heterogeneous.[4] Secondly, even if the relative income distribution remains unchanged while average incomes grow, the food demand will grow faster in the lower income brackets due to their higher demand elasticity. This alone would make it likely that the CVs of food consumption would decline as average incomes and food consumption grow; similarly, one would presume that drastic rise in global food prices, as witnessed in 2007/08 and again 2010 would have a differential impact on food consumption patterns of different income groups, thereby affecting the CV.

More generally, fixing the CV also means that changes in measured hunger across the world will be driven by changes in the DES. This gives the erroneous impression that changes in hunger over time are largely a problem of 'food availability', rather than changes in entitlements (Sen, 1984) of different groups in the population to access to food. Situations where hunger in a population goes up despite stable or rising DES (e.g., due to a regional national catastrophe, rising food prices, conflicts, etc.) are ruled out by definition this way; any change in entitlements across population groups would immediately imply a change the CV. Thus to study hunger, one needs to examine entitlements of groups which can be affected as much by food prices, employment, and wages as by food availability in the country; such assessments would lead to a changing CV.

Lastly, a more technical issue is whether the CV is actually the best measure of dispersion to estimate and apply in this case. As is well-known, the CV is particularly sensitive to the distribution of calories in the upper parts of the caloric distribution. The use of the CV is consequently problematic for two reasons. First, it is not ideal to use a distributional indicator that will be heavily influenced by the distribution of calories among the 'non-hungry'. Second, as a result of the sensitivity to high levels of caloric consumption, any measurement error among that group of 'non-hungry' will have an important impact on the resulting CV and the hungry. There are ready alternatives to the CV, including the Atkinson inequality measure (see Atkinson, 1970) or the Theil family of inequality measures which are both sensitive to the distribution of calories at the bottom end of the distribution, which is of interest here.

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[3] This 'plausible range' is based on the analysis of realistic variances of food intake levels within hypothetical populations with highest and lowest food energy supplies per person.
[4] See, for example, Gruen and Klasen (2003) for an analysis of these trends.

Minimum Dietary Energy Requirement (MDER)

The third key parameter of the FAO method, the minimum requirement of dietary energy, is defined as the consumption level that will balance energy expenditure. Questions raised regarding the approach concern the assumptions determining the dietary energy requirements of different age-sex groups and the rationale for a singular country-specific cutoff point.

(1) Are the assumptions determining the dietary energy requirements of different age-sex groups correct? Components of energy expenditure comprise the basal metabolic rate (BMR), i.e. the energy expended for the functioning of an individual in a state of complete rest; the energy needed for digesting food, metabolizing food and storing an increased food intake; and the energy required for performing light physical activities, both work and non-work. The BMR ranges between 1300 and 1700 kcal/day for adults, depending on age, sex, height and body weight, to which 55 or 56 percent are added for light activity of male and female adults, respectively. For children, the energy required for growth is taken into account. An allowance is also for children below age two from developing countries for the energy needed to recover from frequent infections. For women during pregnancy and lactation, the energy required for the deposition of tissue and secretion of milk is considered. As FAO specifies these dietary energy requirements in accordance with the recommendations by the Joint FAO/WHO/UNU Expert Consultation on Human energy (FAO, 2001), it is assumed that the assumptions are realistic. However, further research is needed to examine the realism of the assumptions in the light of various critical reviews.[5]

(2) Is a singular cutoff point a good approximation of a population's minimum dietary energy needs? The minimum per capita dietary energy requirement is derived by aggregating the estimated sex-age-specific minimum dietary energy requirements, using the relative proportion of the population in the corresponding sex-age groups as weights. As the sex-age distribution of the population changes over time, this so-called cutoff point is being regularly adjusted to demographic change (FAO, 2003). Svedberg suggested that this method has a "built-in flaw that leads to biased estimates" (Svedberg, 2002, p. 6) because it fails to consider that even after taking into account the effects of age, sex, activity and body weight, individuals differ in their energy requirements due to differences in the efficiency of energy use. He suggests therefore replacing the singular cutoff point by a bivariate distribution according to which the probability of an individual not meeting the food energy requirements is not only determined by the distribution of food intake but also by the covariance between food energy intake and requirements. According to Svedberg, following this approach would as such result in a notably higher incidence of undernourishment. Responding to this criticism, FAO experts showed that if

[5] According to Svedberg, FAO uses a BMR that is unrealistically high for countries in the tropics, thus overestimating undernourishment (Svedberg 2002). In contrast, Smith et. al. (2006, p. 48) use energy requirements that are higher than those used by FAO, averaging 2050 kcal per day as compared to 1800 by FAO. This in itself could explain why Smith et. al arrive at higher estimates of undernourishment than FAO. While both approaches assume the same light activity level, they make different assumptions regarding the level of the requirements for given age-sex groups. FAO classifies a person as undernourished that consumes less than the minimum dietary energy requirement (MDER) for the respective age-sex group, whereas Smith et. al. classify all people as undernourished who consume less than the average requirement.

intake is indeed correlated with requirement, all intake levels falling within the range of variation of requirement are expected to match requirements so that the bi-variate formula reduces the cutoff point (FAO, 2003, p. 31). This discussion underlines the importance of further research on the best way of accounting for the non-determinate nature of food energy requirements.

Ex-Post Projections to the Current Year

Due to the delays in the availability of complete FBS data the FAO estimates are published with a considerable delay of three years. For example, SOFI 2010 covers the three-year-average of 2005-2007. Beginning with the 2008 edition of SOFI, FAO started publishing preliminary estimates that extend up to the year of publication. These estimates are based on ex post projections using recent data covering cereals, oils and meats available for human consumption. These commodities cover 80 percent of dietary energy supplies. The effect on undernourishment is projected using the historical statistical relationship between the quantities of those commodities and past estimates of undernourishment. The estimates are published at global and regional levels, not for individual countries.

This extension of the FAO method is a welcome response to demand for timely information and concerns about the impacts of recent developments, e.g. the soaring food prices on food security. However, an assessment of the methodology is not yet possible as a full documentation is not available. To which extent these ex-post projections anticipate the regular FAO estimates, can only be seen when the data for 2008 will be available in FAOSTAT. This will be the case for the first time in SOFI 2011.

Ex-Ante Projections Using The FAO Method

Occasionally, FAO also publishes ex-ante projections of undernourishment as part of its occasional long-term perspective studies for world agriculture. Basically, these projections derive the number of undernourished from projected per caput consumption, intra-national inequality of food availability, dietary requirements and population, using the same method as for the regular measurements.

In its latest long-term perspective study, FAO projected further increases of consumption levels for 2030 and 2050 (FAO, 2006). In spite of increasing energy requirements due to rising shares of adults in total populations and to growing body weights and heights a further reduction of the coefficients of inequality of food availability and a slowdown of population growth, a decline in the number of undernourished was projected. This positive trend is in obvious contrast to FAO’s own monitoring of recent developments, which show the number of undernourished on the increase in spite of growing per caput consumption. Alexandratos (2009) has recently undertaken an evaluation of the reasons for this discrepancy. After revising the earlier projections using all data and parameter revisions which FAO had to introduce due to adjustments of country reports (including higher population growth) up to 2003/2005, the revised projections came indeed rather close to FAO’s estimates for that three-year period, implying that the main reasons for false projections were subsequent parameter and data revisions. However, as both FAO’s ex-post estimates and ex-ante projections use the same concept, it is not really possible to draw conclusions for the real quality of projections As Alexandratos (2009, p. 20) also states, “We cannot avoid posing the question whether the most recent estimates indicate a real reversal of the trend towards gradually and slowly declining numbers of undernourished or is it just data noise? “

Overall Assessment of the FAO Method

The best way of evaluating the accuracy of the FAO method is by way of examining the scientific soundness of the various assumptions and parameters, verifying the correctness of the data inputs and comparisons with other methods. The latter will be done in the subsequent parts of this paper.

The basic problem associated with the FAO method is presumably not the choice of the theoretical approach, but uncertainties and gaps in the data base and parameters. This is indeed a serious point as one can show that the global estimates react rather sensibly to even small changes in the key parameters (DES, CV, MDER), which could well lie within the range of normal confidence intervals. Figure I A-2 shows the results of some simulations, using the spreadsheet of the data inputs for the latest estimate of undernourishment in 2005/2007. As the Figure shows, the global number of undernourished responds particularly sensitively to variations in the key parameters, in particular the DES and MDER values. The elasticities of the global number of undernourished with regard to changes in the national DES, CV and MDER parameters are, respectively, 4.8, 1.6 and 4.7. As stated before, one conclusion so far is that more care should be taken in interpreting the year to year changes of FAO’s estimates.

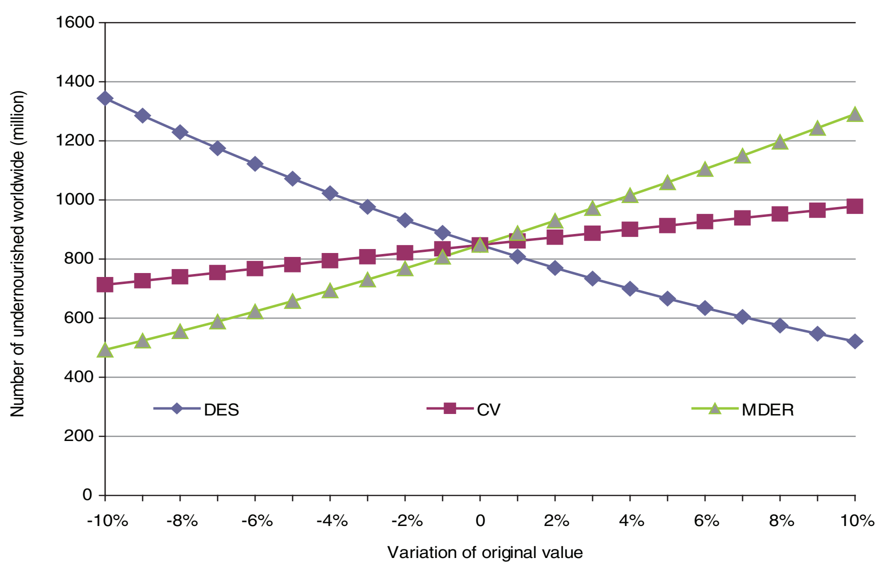

FIGURE I A-2: Sensitivity analysis of the three key parameters of the FAO method for 2005-2007.

The only comparable institutionalized system estimating food security of 70 developing countries is the regular Food Security Assessment by the USDA. Like FAO it compares food energy consumption with food energy requirements. While the estimates are based on FAO's production assessments, the nutritional standards for food energy requirements are less differentiated and the cutoff points generally higher than those calculated by FAO. A full comparison of the two approaches is not possible due to different scenarios and assumptions. However, it is interesting to note that the USDA estimates of undernourishment in the 70 countries tend to be higher than those by FAO. (http://www.ers.usda.gov/Publications/GFA21/GFA21.pdf).

3. HOUSEHOLD CONSUMPTION SURVEYS

Survey Format Useful for Nutritional Analyses

Surveys conducted with the purpose of measuring household living standards usually contain a module on household expenditures. The reason is that expenditures are considered a more reliable indicator of living standards than income (Deaton, 1997). The World Bank also uses the expenditure modules for compiling its poverty statistics. Often, the general World Bank format for Living Standards Measurement Surveys (LSMS) is followed. But details of the survey instruments still vary between countries and situations. Nationally representative household surveys are usually planned and carried out by the individual countries' statistical offices, sometimes supported by other national and international organizations. Depending on the size of the country and the resources available, they contain from a few thousand up to more than 100,000 household observations. For many developing countries, surveys are available for individual years, either through the national statistical offices or the World Bank (http://www.worldbank.org/lsms). In some countries, living standard surveys are carried out regularly, so that data sets exist for several years, while for other countries no data are available at all.

When the expenditure module of some living standard surveys only considered monetary values spent on broad aggregates of purchased goods (e.g., food, housing, transportation, education), these data can hardly be used for detailed nutritional analysis. This is the case for some countries, especially in older surveys. However, the survey formats have generally improved over time. Since poor people tend to spend a significant part of their total budget on food, expenditure modules of recent living standard surveys often comprise a relatively detailed breakdown of food expenditures, including food quantities and monetary values. In most cases, expenditures are defined broadly; in addition to market purchases, self-produced foods as well as food gifts and transfers are captured. Hence, all food that enters the household over a certain recall period is measured, so that a reasonable indicator of household food consumption can be derived. This is also the reason why we use the term "household consumption surveys" here to refer to all living standard surveys that contain detailed information on food quantities consumed at the household level, regardless of the source.[6]

Summary Description of the Assessment Method

Data on the quantity of different food items consumed can be converted to calories and divided by the number of household members to obtain per capita calorie consumption estimates. Alternatively, consumption per adult equivalent can be calculated through weighting household members by age and sex. Comparison of these consumption estimates with energy requirement cutoffs allows one to identify households in which members are undersupplied with calories. In so far as surveys are nationally representative, the share of households in the sample falling under the cutoff can be interpreted as the prevalence of undernourishment in the country. This method has been used in the literature, mostly concentrating on individual countries (e.g., Dowler and Ok Seo 1985). It has not yet been used for providing a global overview of hunger and food insecurity.

The mentioned IFPRI study by Smith et al. (2006) has used such household consumption surveys to calculate the prevalence of undernourishment in 12 African countries. Smith et al. also proposed to use this approach to replace or improve the FAO method. Unlike FAO, which starts from macro level FBS, the survey based approach measures calorie deficiency at the micro level where it actually occurs. As fewer assumptions have to be made, and the micro data are more reliable in principle, the household survey approach has clear advantages over the FAO method. However, the approach is also not without its problems. In the following, we will discuss related advantages and disadvantages.

Advantages of the Consumption Survey Based Approach

When using household level data from high-quality and nationally representative surveys, the information on calorie consumption and deficiency of people is more accurate than when macro level data are used. The reasons are fourfold. First, food consumption is measured where it actually occurs, so that fewer assumptions about lacking data on agricultural production, trade, post-harvest losses and non-food uses have to be made. Commonly, household consumption surveys use 14 or 30 day recall periods for food items. Longer recall periods can lead to unacceptable inaccuracies. There are also a few consumption surveys that use a 7-day recall period, which is preferable from a nutritional perspective.[7]

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[6] Other authors use the term "household expenditure surveys" in this connection (e.g., Smith et al. 2006). We prefer "consumption" over "expenditure", because the term "consumption" makes more explicit that data on physical quantities of food are included and that self-produced and other non-purchased goods are also captured.

[7] Another survey format is a 24-hour recall, which does not measure the food entering the household but the food actually eaten by household members during the past one day (Gibson 2005). Therefore, actual food intake is measured, which is more accurate than food consumption from a nutritional point of view. Twenty-four-hour recalls are often broken down by the different meals and snacks taken; sometimes, food intakes are also disaggregated by individual household members, so that issues of intra-household distribution can be analyzed (Haddad and Kanbur 1990). However, 24-hour recalls are usually carried out for specific nutritional purposes and are not included as part of standard living standard surveys.

Second, in household food consumption data—as opposed to FBS—the foods considered better reflect what is actually consumed (e.g., milled rice vs. unmilled paddy). Some consumption surveys consider more than 150 different food items, although there are also other surveys where the number is below 50. A high disaggregation of food items is generally preferable, because the conversion of food quantities into calories can be made with greater precision. This also allows one to go beyond calories and analyze the degree of dietary diversity or the prevalence of micronutrient deficiencies (Stein, 2006; Ecker and Qaim, 2010).

Third, unlike FAO, which calculates mean dietary energy supply at the country level and then assumes a distribution within the population to derive the prevalence of undernourishment, distributional assumptions are not necessary when household survey data are used. The reason is that the analysis is carried out for all households in the sample, so that the data themselves determine the distribution. This is also the reason why the household survey approach is sometimes referred to as a non-parametric method (Ricardo et al., 2007).

Fourth, while FAO uses data on the average population structure at the country level to derive minimum dietary energy requirements, the survey-based approach takes the actual demographic structure of households into account. This is one reason why the mean energy requirements may differ between the approaches.[8]

Beyond data accuracy, another big advantage of the survey based approach is that it allows a disaggregation of food insecurity by geographic areas or socioeconomic groups within countries. Such "hunger mapping" provides actionable information for policy responses at sub-national levels. Moreover, in addition to merely describing the situation of food insecurity, causes and determinants of undernourishment can be analyzed, because consumption and living standard surveys also include data on a multitude of socioeconomic household characteristics, such as educational levels, occupation, ethnicity, and infrastructure conditions, among others. Likewise, food consumption data can be used to determine the income and price responsiveness of food energy and nutrient consumption, which is crucial in order to predict nutritional impacts of policies and external shocks (Behrman and Deolalikar, 1987; Ecker and Qaim, 2010).

Disadvantages of the Consumption Survey Based Approach

While household surveys may achieve a higher data accuracy in general, there are also some weak points and disadvantages of the household survey method with respect to measuring energy and nutrient consumption. First, surveys that are carried out in a single round may not properly capture seasonal variation in food consumption.[9] This can be a particular problem in rural areas where seasonal fluctuations in consumption are more pronounced than in urban areas. It should be stressed that many surveys account for this problem by collecting data in seasonal waves or by extending the survey over a 12 months period (Smith et al., 2006). If household surveys are evenly spread over the year, unbiased estimates of mean consumption levels may indeed be obtained, but the individual household data may still be biased.

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[8] Other possible reasons include different assumptions about people's physical activity levels and body mass index (FAO/WHO/UNU 1985, Svedberg 2000). Such assumptions have to be made irrespective of the underlying measurement approach.

[9] As noted above, the FAO method is also not able to capture this variation.

Second, while food entering the household is captured relatively well, food eaten away from home is often not properly accounted for. In a survey, it may be relatively easy to elicit the value of outside meals consumed, but details about the exact food items consumed away from home, which are needed for converting into calories, are much more difficult to obtain. This can be of particular importance for households where members eat regular meals at work or in school. In such cases, actual calorie consumption will be underestimated (Bouis et al., 1992).

Third, and related to the previous point, in so far as consumption surveys measure the total food entering the household, they do not capture waste, losses and non food use within households. As some amounts might be fed to pets, wasted, or given to guests or hired laborers, one cannot rule out an overestimation of actual food intakes, especially in richer households (Bouis, 1994).

And finally, there may be non-sampling errors caused by general issues of misreporting and mis-recalling, un-completed questionnaire forms, retroactive corrections by enumerators etc. The risk of mis-recalling by survey respondents usually increases with the length of the recall period chosen in the survey format.

Some authors have also voiced more general criticism related to nutritional assessment studies based on household survey data, especially in terms of determining the prevalence of deficiencies using general cutoff levels (e.g., Gibson, 2005; Svedberg, 2000). Reference levels for energy requirements are defined for the average daily need over a reasonable – but usually unspecified – period of time that might not be properly reflected in a food recall. Moreover, they are defined for groups of individuals of the same sex, age, and physiological status and refer to intake levels required to maintain good health and development in healthy and well-nourished people on average (FAO/WHO/UNU 2001). Thus, the requirements are recommended to be applied to population groups rather than to individual persons or households. Therefore, when using survey data, results on the food energy status of individual households should be interpreted with caution, although results for the sample as a whole, or for certain sub-samples, should not be affected. Indeed, Smith et al. (2006) showed that summary results of household level analyses hardly differ from the results of more aggregate analyses for population groups.

Overall Assessment of the Consumption Survey Based Approach

The household survey based approach has several advantages over the FAO method, especially in terms of the micro level data being used, which captures household food availability and access much better than is possible with food balance sheet data and distributional assumptions. Analysis based on household consumption surveys also yields more actionable information, because the results can be presented in a disaggregated way and used for policy analysis and predictions of nutritional impacts of shocks and policy changes at sub-national levels. Another plus is that the household data are collected and owned by national statistical offices, so that a bigger degree of national ownership is likely when these data were to be used for a global food security assessment by international organizations. However, a clear limitation for using household consumption surveys for regular global food security assessments is the bigger amount of data required as well as its timeliness. While the availability of living standard surveys has improved significantly over the last 10 years, there are still many countries for which no nationally representative food consumption data are available at all, let alone a series of updated surveys in regular intervals. Until all countries can afford to conduct representative national household surveys on a periodic basis, this approach to measuring hunger cannot substitute but merely provide a complementary perspective to the FAO approach based on FBS.

4. ANTHROPOMETRIC MEASUREMENTS

While the first two approaches to measuring food insecurity and malnutrition essentially measure inadequate food consumption at household level as a proxy of poor nutritional status of a population, anthropometric measures assess the nutritional outcomes at the level of the individual. The schematic diagram below illustrates these linkages. It shows that one need not presume that measuring food consumption or nutritional outcomes will produce similar results. There are range of intervening factors that affect the transformation of food availability and food purchases into nutritional status. Among them are intra-household losses, unequal intra-household distribution, and, most importantly, heterogeneity at the household level in transforming food intake into nutritional status which will depend on the difference in disease exposure, activity levels, and individual heterogeneity in metabolism and food processing. Also, the anthropometric approach is non-specific with regard to which particular nutrients might be lacking (or in excess supply). Thus these approaches are essentially measuring different concepts that may, however, complement each other. In this section we will discuss the methods and advantages and disadvantages of anthropometric indicators. The section will draw heavily on Klasen (2008) where these issues are discussed in some more detail.

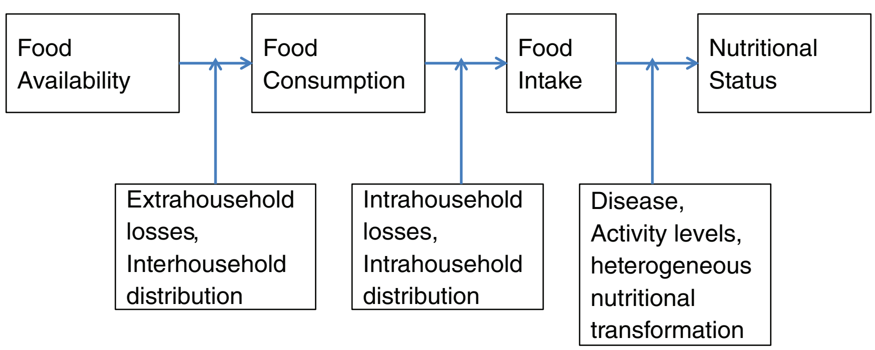

FIGURE I A-3: Levels of measuring different aspects of food and nutrition insecurity.

Indicators of Anthropometric Measurement

While there is a very broad range of anthropometric measures that can be used for an assessment of nutritional status (see WHO 1995), the most commonly used indicators all relate to height and weight of individuals. Given that height is unchanged for adults but changing for children, anthropometry has different indicators for both groups. In fact, the greatest consensus as far as assessing anthropometric status is concerned, exists using anthropometric indicators of children aged 0-5; they will therefore be the focus of the discussion here. The three different most commonly used indicators, stunting, wasting, and underweight offer insights on different dimensions of nutritional problems. Wasting (low weight for height) is an indicator of acute undernutrition particularly relevant in famines and to monitor acute food shortages. Stunting (low height for age) is an indicator of chronic undernutrition focusing on persistent nutritional deficiencies, and underweight (low weight for age) is a summary indicator combining both facets.

These indicators are usually determined with the help of a Z-score, which is calculated by dividing the difference between the age-and sex-specific anthropometric indicator of an individual child (e.g., height of a girl aged 38 months) and median of the same indicator from a reference population by the standard deviation of that indicator in the reference population.[10] What this indicator thus measures is the distance (expressed in standard deviations) of the anthropometric performance of the child from the median of the reference population. If the Z-score is less than -2, moderate undernutrition is assumed, if the Z-score is less than -3, severe undernutrition is held to exist (UNICEF, 1998).

Two points are worth noting. First, the cut-offs are chosen with a probabilistic interpretation. A Z-score of -2 suggests that, given genetic variability, there is a roughly 95 percent chance that the individual child is indeed suffering from undernutrition. If this interpretation is used, the type II error of this assessment is huge, i.e., most children with a Z-score of between 0 and -2 (and quite a few with a Z-score above 0 but with genetically tall or heavy parents) could well be suffering from undernutrition which would systematically underestimate childhood undernutrition at the population level. An alternative interpretation of the choice of these cut-offs is that only serious nutritional deficiencies relative to the standard should be counted as undernutrition, and thus children with a Z-score between 0 and -2 should not be included.[11]

Second, the calculation of the Z-score critically depends on the reference standard. Until 2006, the recommended reference standard had been constructed using two sets of children from the US. For a number of conceptual and technical reasons (see WHO, 1995), this standard was seen as problematic and in 1994 WHO decided to undertake a multi-center child growth study to derive a new reference standard (WHO, 1999).

Such a new international standard was recently published in 2006 (de Onis and Garza, 2006). It is based upon the growth and weight development of children in six countries (Brazil, Oman, Ghana, India, USA, and Norway) where a sample of children was monitored that followed WHO feeding guidelines and were not constrained by inadequate access to nutrition or health care. In the four developing countries, this involved selecting children from extremely well-to-do backgrounds to ensure that they were not in any way hampered in their growth potential (WHO, 2006b).

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[10] This was the exact procedure when the old reference standard was still being used; since the new reference standard is not exactly normally distributed, the calculation of the Z-score is a bit more complicated to reflect the deviation from normality.

[11] In addition, interpreting a Z-score of an individual child generates further problems as there clearly are genetic influences of the parents on weight and height of their children. Thus individual children might be falsely identified as well nourished or undernourished. Thus using these cut-offs can only usefully be applied at higher levels of aggregation where presumably these inter-individual genetic differences cancel out.

Two further points are worth noting. First, in contrast to the previous standard which was based on the descriptive height and weight development of two samples of U.S. children, the new standard is explicitly constructed as a 'normative' standard of 'optimal' child growth and weight development (de Onis and Garza, 2006). To achieve this, only children were enrolled in the study where parents were of high socio-economic status, were non-smokers and (largely) followed the WHO recommendations on infant and child feeding (including particularly the use of exclusive breast-feeding). In addition, children that fell ill, were obese, or strongly fell behind in growth and weight gain were dropped from the final calculation of the standard. Second, since the growth and weight charts of the children in the six countries looked very similar, a decision was taken to pool them to create a single new growth standard from the pooled data (WHO, 2006a).[12]

As a result of using different populations and these various changes in the approach to generating a standard, the switch from the old to the new growth standard has typically meant that rates of stunting and wasting have gone up while rates of underweight have gone down (e.g., Misselhorn, 2010; Drèze and Deaton, 2008).

For children beyond five years of age and adolescents, there is no similar consensus on a growth reference standard. Also it appears that genetic differences and, in the case of girls, the age at menarche which varies across populations makes it quite difficult to design a universal growth standard (e.g. WHO, 1995; Butte et al., 2007).

For adults, there is also not such a clear consensus on what anthropometric status constitutes undernutrition. Generally, recourse is made to the body mass index (BMI), defined as the weight (in kg) divided by the square of height (in meters). Usually a BMI below 18.5 is seen as indicating undernutrition (and one below 17.5 is severe undernutrition) but generally the heterogeneity across age, gender, body composition, climate and populations make it difficult to use them as definitive measures of undernutrition. Also, it is not clear to what extent undernutrition using the BMI in adults and undernutrition using wasting and underweight among children are comparable (WHO, 1995; Klasen, 2003).

A final general note is on data availability. Data for childhood anthropometry are collected at regular intervals across the developing world using the highly standardized and high quality Demographic and Health Surveys (DHS, supported by USAID and implemented by MACRO Inc. and national agencies in the respective countries) and related Multiple Indicator Cluster Surveys (MICS, implemented by UNICEF, often in collaboration with national agencies). These surveys use a standardized protocol to measure and weigh children, they are always based on national random (clustered) samples, sample sizes vary from some 3000 to over 100,000 children and they are done at rather regular intervals (usually every five years). Virtually all of these data are freely available in the public domain and are usually published 6-18 months after the field work is completed. Now there are several hundred surveys available for about 100 developing countries, in some cases spanning 6-8 time periods (particularly if the earlier World Fertility Surveys are also included). In fact, childhood anthropometric data are thus much more broadly available (using comparable methods and procedures) than household survey based assessments of food consumption discussed above. Unfortunately, DHS and MICS cannot be

[12] The complete and selected sample of micro data is not yet available beyond the research team that contributed to the new sample so that one cannot precisely identify possible biases that might have arisen from the selection procedures.

merged with data from household consumption surveys, because the two survey approaches are implemented separately by different organizations and based on different samples. There are only very few nationally representative surveys in individual countries that contain both anthropometric and food consumption data.

Advantages of Using Anthropometry Measurements

The use of anthropometry in general, and childhood anthropometry in particular, for the measurement of food insecurity and undernutrition has much to recommend.

First, it is measuring directly what we are essentially interested in: how malnutrition affects the health and well-being of individuals. There is overwhelming evidence that malnutrition that generates poor anthropometric outcomes is a causal factor in leading to higher morbidity and mortality (Pelletier, 1998; Osmani, 1990; Drèze and Deaton, 2008). As children's development (physical and mental) is particularly vulnerable to malnutrition, it is also quite appropriate to focus on childhood anthropometry as a particularly important indicator of undernutrition.

Second, the availability of three different measures gives a good sense of chronic as well as acute undernutrition. It is therefore no surprise that relief organizations regularly use childhood anthropometry to monitor the success of relief operations in emergencies across the (developing) world.

Third, as the data also come from household surveys (mostly DHS and MICS), it has the great advantage that one can (if sample sizes allow) immediately disaggregate undernutrition by groups and regions and thus identify the groups and localities particularly affected by undernutrition.

Fourth, the base in household surveys also allows a direct use for analyzing the causes of undernutrition. The surveys include a wide variety of other variables that can be (and have been) used regularly to assess the factors driving undernutrition. In fact, there is a vast literature that has developed as a result of the wide availability of these indicators of undernutrition using the DHS and MICS (e.g. Smith et al., 2003; Foraita et al., 2009; Kandala et al., 2010). Correspondingly, these surveys can then also be used to design and monitor interventions to reduce undernutrition.

Fifth, the data availability on childhood anthropometry is unusually good with broad and relatively timely coverage for nearly all countries of the world. The use of standardized procedures of the two survey programs (and their policy to make data available free of charge) have made anthropometric data particularly widely available in a highly standardized format so that monitoring of childhood anthropometry using these indicators is feasibly across space and time in ways that is currently not possible using household food consumption-based methods.

Disadvantages of Using Anthropometric Measurements

Despite these advantages, there are a range of issues and problems associated with the use of anthropometry as indicators of childhood undernutrition. Some can potentially be remedied, others are somewhat harder to address.

First, while it is useful to track nutritional outcomes, poor anthropometric status can be the result of things that are unrelated to food security, such as presence of diseases. So we cannot be sure that a country or region with poor anthropometric indicators is necessarily an area where there are food security problems. So depending on what we are interested in, this can be a disadvantage (see first advantage above for a different perspective).

Second, while coverage is wide and timeliness quite impressive, anthropometric indicators are usually only generated every 3-5 years in a country, in some countries even only every 10 years. They can therefore only be used for medium-term assessment of nutritional problems, not for identification of short-term crises or reliable annual statistics on global hunger.[13]

Third, the focus on children neglects, of course, problems of food security among adolescents and adults which may be more or less severe in particular country contexts.

Fourth, small sample sizes often preclude careful disaggregation of anthropometrics by sub-groups or regions or make them statistically unreliable. Related to that are the usual problems of household surveys including the problems of drawing adequate samples in countries where census counts are often not reliable (and lead to great revisions from census to census) so that different samples can lead to incomparability over time (e.g. Drèze and Deaton, 2008).

Fifth, while the surveys used to measure anthropometric shortfalls are quite comprehensive, they lack some critical covariates to better analyze the determinants of food insecurity and undernutrition. Most serious is that neither the DHS nor the MICS include an income or expenditure module. As a result, most studies using these surveys use an asset index as a proxy for income, which partly remedies this issue but does not enable a link to food consumption patterns (e.g. Filmer and Pritchett, 2001). While these are all serious issues and drawbacks, possibly the most serious issues are the following last two we mention here:

Sixth, changes in nutritional practice, often referred to as the nutrition transition, might affect the reliability of anthropometry as indicators of nutritional status. In particular, the worldwide move towards food with a high content in starch, fats, and sugar may affect the way one ought to measure undernutrition. In particular, weight-based measures might be affected by this shift. In the new growth standard, overweight and obese children were excluded as they are not deemed ‘well-nourished’; this procedure has the advantage to be able to more easily identify children suffering from overweight and obesity (including children that are simultaneously stunted and overweight) in the new standard But it can generate problems of interpretation when identifying underweight children. Due to the nutrition transition, many children who have poor access to nutrition and are malnourished still gain sufficient weight as the calories they receive have a high starch, fat, and sugar content. These children, when compared to the WHO growth standard (which excluded overweight and obese children) appear as adequately nourished even though they might not be. As shown by Misselhorn (2010), it appears that underweight indicators, currently the only anthropometric indicators included in the monitoring of MDG One, are improving over time more rapidly than other anthropometric indicators due to this effect and might suggest greater progress in reducing undernutrition than is warranted; stunting, on the

[13] Of course, one can use extrapolation and intrapolation to generate more up to date estimates with broader coverage, as is done for the global poverty counts (e.g. Ravallion and Chen 2008). But a range of possibly debatable assumptions would be required.

other hand, moves much more slowly and might therefore be a preferred indicator of undernutrition that is less affected by the biases introduced by the nutrition transition.

Lastly, there is the question whether one single growth standard is really appropriate for the measurement of children all over the world. The claim that one standard would suffice was backed up by a variety of individual studies and the editorial opinion of major medical journals (e.g., Lancet 1984, Graitcer et al., 1981; Habicht et al., 1974).[14] This view of one reference standard for all children in the world has influenced the development of the new international reference standard (WHO, 1995 and 1999), but it has never been fully accepted by everyone (e.g., Davies, 1988; Eveleth and Tanner, 1990; Bogin, 1988; MacFarlane, 1995). While all agree that environmental factors are much more significant than genetic differences in explaining differences in anthropometric shortfall between populations, quite a few studies suggested that genetic differences are important enough to be considered, particularly for international comparisons of anthropometric shortfalls. Also, it is widely accepted that genetic differences affect the growth and weight development of children beyond 6 and adolescents (e.g., Butte et al., 2007; WHO, 1995).

In this context, it should be pointed out that the preferred measure for international comparisons, the share of children below a Z score of -2 or -3 is highly sensitive to even small differences in the reference standard.[15] In a population such as South Asia's, where about 50 percent of the population were stunted or underweight in 2000, a difference of only 1 percent in the reference standard would lead to an 8 percentage point drop in the share of underweight children. If we believed the difference is 3 percent, South Asia's rate of undernutrition in 1990 would have been below the rate observed for Sub-Saharan Africa in that year, where there is little evidence of a similar genetic difference in the growth of children, compared to the USA.[16] Thus a large share of the South Asian undernutrition enigma would simply disappear if the reference standard differed by just a minor amount.[17] The data used to create the new standard shed an interesting light on possible inter-population differences in child growth, suggesting that (small) genetic differences appear to exist but which needs further research.[18] For example, from

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[14] This was supported by studies showing that the difference in growth and weight gain between privileged children from developing countries and the US reference standards were very small (Martorell et al. 1988, Habicht et al. 1974, Graitcer et al. 1981, WHO 1995, Ramalingaswami et al. 1996, Bandhari et al. 2002).

[15] For example, even those who favor one standard suggest that genetic differences between South Asian and US children amount to about 1 cm of height difference by age five (WHO 1995). Other researchers believe that the difference is a bit larger, on the order of 1-3 cm between well-to-do children in the USA and in South Asia (Bogin 1988, Davies 1988, Eveleth and Tanner 1990, MacFarlane 1995). One cm constitutes less than 1% of the median height at age 5 for boys (109.9 cm), and even 3 cm would be less than 3% (WHO 1983).

[16] In fact, there is some evidence suggesting that African children grow faster (e.g. Martorell 1988, MacFarlane 1995) than US children; others suggest that the variability of growth and weight gain in Africa is much larger than elsewhere, related to the higher genetic diversity of Africa's populations, which in turn is consistent with humanity's origin in Africa (Kidd et al. 1996). This would make a single standard from the USA not suitable to assess undernutrition in the genetically more diverse African context.

[17] The reason for this surprising sensitivity of the undernutrition rates to small changes in the reference standard is related to the fact that in a country with high undernutrition rates, the mode of the Z-score distribution is close to the cut-off of -2.

[18] Even though the selection procedure of enrolling children was such that it would minimize and possibly bias downward inter-population differences, it nevertheless remains the case that small differences between the countries considered are found. As shown in WHO (2006c), mean heights in India and in Oman are between 0.5-2% smaller than in the pooled sample at different ages, and the differences are about twice as large compared to children in

Bandhari et al. (2002), who assess the Indian sample of children, one can deduce that the children in the sample used for the new reference standard had an average Z-score of -0.45 (compared to the old reference standard). This would be roughly equivalent to a 3.5 percent lower weight for age of these children compared to the new standard, thus confirming a genetic difference of about 3 percent in weight.

These pieces of evidence suggest that the consensus in the literature of about 1-3 percent lower growth potential of South Asian children compared to children in the US, Europe, or Africa continues to hold. Applying one reference standard might therefore, in a comparative sense, overestimate undernutrition in South Asia by between 8-20 percentage points.[19]

Overall Assessment of Anthropometric Measurement Approaches

Despite the mentioned disadvantages, it is clear that anthropometric evidence provides critical insights into the prevalence and development of undernutrition across the world. Particularly childhood anthropometry is well developed with clear methods, indicators, and available data that can be used for studying the prevalence and drivers of undernutrition, and also to assess the impact of policies on undernutrition outcomes. It is eminently possible and useful to use these indicators to measure and analyze undernutrition.

At the same time, data availability and timeliness, the issues regarding the nutrition transition, and the question of genetic differences pose some difficult questions regarding comparisons across space and time of these indicators. On the availability, timeliness and completeness of the survey instruments, improvements are feasible. The most obvious improvement would be to regularly link household surveys that contain income and expenditure (consumption) modules with anthropometric surveys. Currently these survey programs run separately and some integration would clearly be possible. Regarding the other issues, more research is needed to assess to what extent one can remedy the possible biases introduced by the nutrition transition (where recourse to the stunting indicator might be the preferred solution) and genetic differences across populations.

5. COMPARING THE THREE METHODS

Contradictions and Complementarities between Indicators

We already commented above on the apparent incongruence between assessment of food insecurity based on the FAO method and food expenditure/consumption based methods for a sample of Sub-Saharan African countries. The IFPRI study showed higher rates of food

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Norway and Brazil, the tallest group in the sample. Particularly noteworthy is also that 5 year old children in India were about 2% shorter than in Ghana.

[19] To be sure, this would not suggest that undernutrition is not a problem in South Asia; nor would it be able to account for the puzzling finding that undernutrition rates are falling very slowly there despite high economic growth. On this, see Drèze and Deaton (2008) for a discussion.

insecurity using household consumption surveys and a different ranking of countries (Smith et al. 2006).

Similar problems appear when comparing the FAO method with indicators of childhood anthropometric shortfall. While one would, for reasons discussed above, not assume a perfect congruence, the divergence in the regional distribution of undernutrition using these two approaches is staggering. Figure I A-4 below shows a scatterplot of undernourishment rates using the FAO method and the prevalence of underweight children for a sample of countries around the year 2000. The correlation is quite weak. Of particular note are the remarkably high rates of underweight in countries of South Asia, compared to their much better performance in terms of the FAO undernourishment indicator. Conversely, in many Sub-Saharan African and some Caribbean countries, undernourishment is high but underweight comparatively moderate.

The problem is compounded when one confronts childhood underweight rates with under five mortality rates for the same sample of countries (see Figure I A-5). Given the health problems associated with undernutrition, one would expect a fairly strong correlation, but again the correlation is not as strong as one would expect. Of particular note is that now the South Asian (and some East Asian) countries stand out with particularly high childhood undernutrition but comparatively low under five mortality rates.

The puzzle of the high childhood undernutrition indicators in South Asia has commonly been referred to as 'the South Asian enigma' (e.g. Ramalingaswami et al. 1996). Some have suggested that it is related to low status of women there, leading to the poor anthropometric outcomes for children. Yet even the most careful assessment of this factor available to date (Smith et al. 2003) was unable to explain the high rates of childhood undernutrition there, even once women's status was explicitly accounted for. In fact, Klasen (2008) has shown that cross-country models of explaining undernutrition regularly fail to explain the high rates of undernutrition in South Asia, corroborating the suggestion that comparability issues associated with the reference standard might be empirically relevant as well.[20]

Thus major unanswered questions remain regarding the actual regional distribution of food insecurity and undernutrition and much may be related to the shortcomings of the various indicators which we discussed above.

[20] As already mentioned above, there is a second South Asian enigma referring to the very slow improvements in anthropometric indicators despite rapid economic growth and poverty reduction. This cannot be due to possible problems with anthropometric standards and is similarly puzzling as the already reported decline in per capita food consumption referred to above. See Drèze and Deaton (2008), among others, for a discussion.

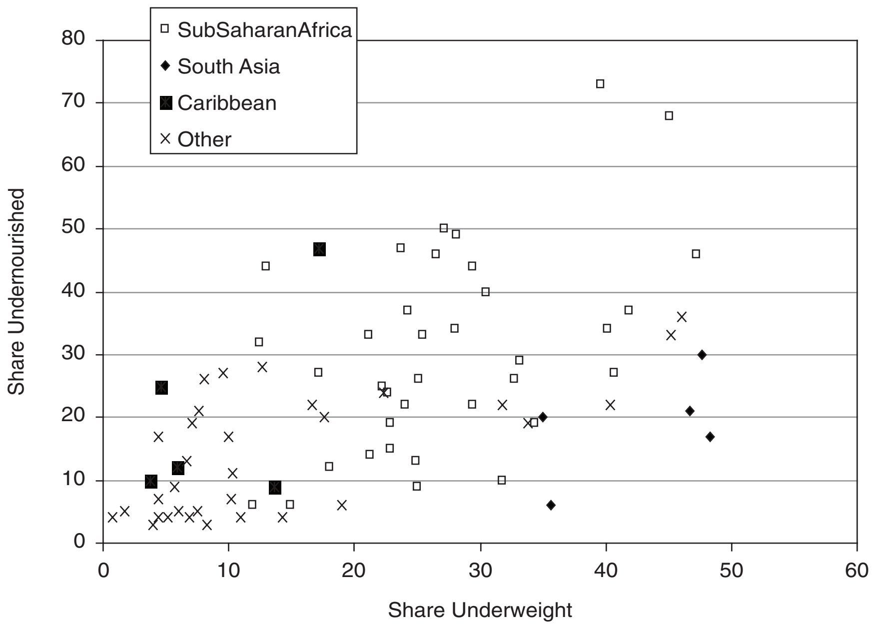

FIGURE I A-4: Undernourishment and childhood underweight rates in 2000.
SOURCE: Klasen (2008)

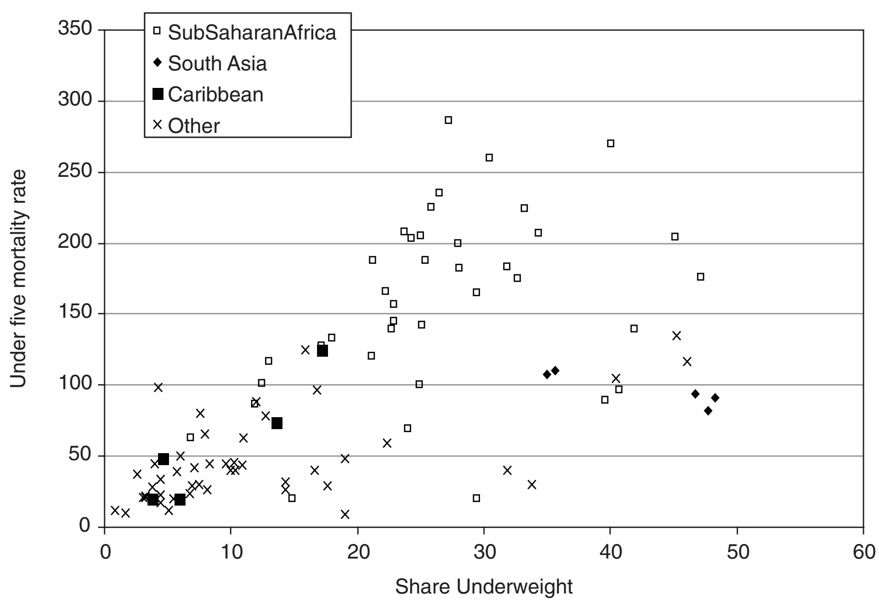

FIGURE I A-5: Childhood underweight and under five mortality rates 2000.
SOURCE: Klasen (2008).

The Three Key Methods in Comparison

All three indicators discussed—the FAO approach, the household food consumption survey based approach, and the anthropometric approach—have their strengths and weaknesses, but the evaluation also much depends on the specific purpose in mind. Table I A-1 tries to summarize how each approach performs with respect to different criteria that we consider important. The assessment is based on the indicators as they are currently being used and on present data availability. As can be seen, the different approaches are complementary. Each approach, as well as data availability, can be improved, which might change the performance related to some, but not all, criteria. Such possible improvements are discussed in section 6.

TABLE I A-1: Performance of three assessment approaches as currently in use with respect to different criteria

Criterion	Undernourishment (FAO approach)	Consumption survey	Anthropometry
Ability to draw a regular picture for total global, regional and national populations	++	-	+
Ability to draw a regular picture for special population groups at global level	-	-	++
Usefulness to assess inequality of food consumption within countries	--	++	--
Usefulness to assess consumption consistent with national supply and demand	++	-	--
Accuracy in terms of measuring the adequacy of food intake	+	++	--
Accuracy in terms of measuring and identifying determinants of nutritional status at a point in time	-	+	++
Accuracy in comparing nutritional status across space and over time	--	+	?
Ability to assess dietary diversity and micronutrient status	--	++	-
Ability to portray regional and socioeconomic heterogeneity within countries	--	++	++
Ability to portray seasonal variation	--	-	-
Ability to inform global governance	++	-	++
Usefulness to guide national policy decisions (e.g., targeting)	--	+	++
Usefulness to simulate nutritional impacts of policies and shocks at country level	--	++	-

Notes: + and – signs indicate whether or not the approach is suitable. Double signs indicate very suitable or very unsuitable.

As can be seen, none of the three approaches has a clear advantage in meeting all criteria. In particular, there is no conclusive evidence regarding the accuracy of the three approaches in assessing the prevalence of undernourishment or undernutrition. The consumption survey and anthropometric approaches have clear advantages over the FAO method in several criteria, especially in terms of measuring diversity and heterogeneity within countries. Although currently hardly done, they could potentially serve to generate even more information that is important for a complete assessment. For example, household consumption surveys are potentially very useful to assess dietary diversity and micronutrient status.

While the analysis so far leads to the conclusion that there are several reasons to suspect that the FAO method generates biased estimates, the direction of the likely biases cannot currently be conclusively stated. On the other hand, the approach has the advantage of drawing a regular picture, consistent with national aggregate food production and trade statistics, of undernourishment for the population as a whole at national levels and above, which may be useful for global governance and discussions on hunger and ways to combat it.

6. OPTIONS FOR IMPROVING FOOD SECURITY AND NUTRITION INDICATORS

In 2002, FAO organized an International Scientific Symposium on Measurement and Assessment of Food Deprivation and Malnutrition, which considered all major methods including qualitative methods for measuring people's perception of hunger. There was wide consensus that "no single method can capture all aspects of hunger while at the same time providing policy-makers with relevant and timely information in a cost-effective manner" (FAO, 2003, p. XV). Accordingly, the Symposium concluded that a 'suite' of indicators was needed to cover the different dimensions of food security. We believe that this conclusion is still valid.

One of our central suggestions for improving and broadening the empirical data base is running more surveys. In the longer term, a regular availability of results from representative surveys could greatly enhance the worldwide information on food insecurity and malnutrition and reduce the need for additional indicators derived from macro food balance sheets. However, even if this suggestion is followed, data availability would only improve gradually. Moreover, the possibility of inconsistent and non-representative household data could still not be ruled out. Therefore, our recommendations are twofold. First, the FAO method should be improved through better data and more transparent science-based assumptions. Available data from household consumption surveys can be used to improve the FAO parameter assumptions. In this connection, lessons about how to deal with missing data through interpolation can be learned from the World Bank, which uses living standard surveys to compile global poverty statistics and updates in certain intervals. Second, household consumption survey and anthropometric approaches should be further improved, both conceptually and through improved data bases. These recommendations are further elaborated in the following.

Improving the FAO Indicator

At the outset it should be noted that the experts in the FAO Statistics and Agricultural Development Economics Divisions are currently fully aware of the weaknesses in the methodology for estimating undernourishment. Work is underway to improve both the data base and part of the methodology. Many critical points need to be addressed of which several are currently under consideration in FAO. Of importance are in particular the following:

Food consumption: Continuing the overall reform of FAOSTAT with the view to improve the quality and consistency of all data inputs for the FBS. The aim should be to improve the estimates of daily dietary food energy supplies. Whereas consumption has so far mostly been compiled as the balance of supply-utilization accounts (SUA) for the various commodities and foods, efforts should be promoted, working with national authorities, to reconcile the estimates with survey data. Improved estimates will also be needed for other significant components of the FBS, namely food waste and losses inside households and commercial kitchens. Given the overwhelming importance of the DES estimate for the FAO hunger measure (and many other important uses of these data), improvements in the accuracy of these estimates is a top priority.

Intra-national inequality of food consumption: Examining the validity and updating of the coefficients of variation (CV) of food consumption. Efforts currently underway in FAO to improve the measures of inequality using household surveys are to be supported. Close cooperation with national and international organizations conducting such surveys is recommended so as to ensure consistency of the foods included and possibility of regular updates to reflect change of CVs over time.

Minimum dietary energy requirements. Continuing inter-agency cooperation to determine best science based estimates of MDERs. Regular updates are needed to reflect the effects of changing age structures (in particular rising shares of adults in populations) and changing heights and weight standards.

Moving Beyond the FAO Indicator

Even with the suggested improvements, the FAO method would not satisfy all information needs with regard to food insecurity, nor would it suffice to provide policy makers with actionable information needed to address the main obstacles to overcoming hunger and malnutrition through effective food security strategies at country level. For these purposes, consumption surveys and anthropometric measurements are much more useful, but there is also substantial scope for improvement of these approaches. In our view, the most important ones are the following:

Data availability: Improvements are required, especially with respect to nationally representative household consumption surveys, which are usually integrated in more comprehensive living standard surveys. Such living standard surveys with sufficiently disaggregated food consumption modules should be carried out more frequently, and in a larger number of countries, to improve the micro level information base. This will require additional resources, but such data can be used for a variety of purposes. Beyond the food security context, nationally representative household surveys can be used for tracking all sorts of developments at the micro level and for planning and evaluating policy interventions. To the extent possible, the survey formats should be standardized internationally.

Anthropometric measurements: Here the data base is much better, but anthropometric surveys contain little other socioeconomic variables and no information on food consumption. As nutrition, health, consumption, and income are so closely related, we propose linking anthropometric surveys with household living standard surveys. This will not only help improve the understanding of food security issues, but will also constitute a precious resource for broader micro level research related to food, nutrition, health, demography and overall welfare.

Research: There are a variety of conceptual issues related to appropriate assumption for minimum energy requirements, anthropometric standards etc., which need further research. Integrated research that compares food intake and nutritional outcome indicators, controlling for other health-related aspects, would be particularly useful to better understand the existing contradictions and complementarities and improve the methodologies. This requires the proposed link between (or integration of) anthropometric and household living standard surveys.

Dietary diversity: More research is also required beyond a calorie focus, to better understand the role, determinants, seasonality and appropriate measurement of dietary quality and diversity. A simple count of different food groups consumed by households (food variety score) has been proposed as a good indicator of nutritional status and even of food security more generally, but questions remain on advantages, drawbacks and limitations of such dietary diversity measures in particular situations (Ruel, 2003). Such research would also benefit a lot from a wider availability of nationally representative linked anthropometric and food consumption data.

Depth of hunger: In SOFI (2000) FAO had published estimates of 'depth of hunger', defined as the extent to which consumption levels of the undernourished fall below requirements. For example, it was shown that, in 1996-1998, 46 percent of countries in Sub-Sahara Africa had an average depth of more than 300 kcal per person per day, whereas this depth was only found in 16 percent of countries of Asia. Publication of this measure was not continued in later issues of SOFI. Indeed, while information on the depth of hunger is of great interest for comprehensive assessments of the state of food insecurity, compiling such an indicator can only add value if the estimates are derived from empirical data with regard to people's real consumption and not from assumptions about the intra-national inequality of food consumption. More research is needed in this field and a resumption of depth of hunger compilations could be considered once the compilation and regular updating of empirically reliable CVs of food consumption has been completed.

Policy impact simulations: Concerning the simulation of nutritional impacts of policies and shocks at country level, household food consumption data currently seem to constitute the best starting point. Since these surveys also contain information on food prices and household incomes or total expenditures, calorie price and income elasticities can be estimated for the population as a whole as well as for population subgroups. These elasticities, together with the results on household food security, can then be used to predict changes in the prevalence of undernourishment due to price and income changes. Ecker and Qaim (2010) have recently developed such an approach, which beyond calories also captures micronutrient deficiencies and related price and income elasticities. Anriquez et al (2010a and b) have also used household survey data to assess the possible effects of staple food price increases on households' food consumption and undernourishment. Of course, there is scope for improvement, but in general the approach seems useful to simulate micro level nutrition effects of food price spikes or economic crises to identify short-term problems that cannot wait for the assessment based on a new household survey. If living standard surveys were linked with anthropometric surveys, as proposed, then such analyses could be extended to also simulate impacts of policies and shocks on the prevalence of child underweight, wasting, and stunting.

7. CONCLUSIONS

Improvements in the metrics of food insecurity and malnutrition are not only urgently needed, but also possible. This assessment of available methods has shown various entry points for improvement. A consistent and fully transparent process is recommended, comprising additional research and stepwise updating of the various indicators. The aim would be to develop an "Integrated Suite of Indicators," in line with the recommendations already made by the International Scientific Symposium on Measurement in 2002. Such a suite would eventually use an improved data base to calculate a reformed FAO hunger indicator, combined with survey and simulation-based estimates of hunger using household expenditure surveys, linked with anthropometric surveys. The proposed process could involve the following three steps:

The agencies involved in the collection of relevant data and compilation of relevant indicators should collaborate through *active networking*. An example for an appropriate institutional framework for such networking could be the emerging global Food Security Information Network (FSIN), which is currently being developed by FAO, WFP and IFPRI. It links the past FAO FIVIMS work with the new FAO corporate strategy on Information Systems for Food and Nutrition Security (ISFNS). This is a promising initiative which could eventually be expanded to include agencies like WHO, UNICEF, World Bank and the EU Commission.

A complete *inventory of estimates of relevant national indicators* of food insecurity and malnutrition should be established, published, and regularly updated. This could not only include the main indicators, the food balance sheet approach of FAO, household surveys and anthropometry, but also, as available, other useful indicators such as micronutrient deficiency and dietary diversity. The inventory would contribute to greater transparency and enable more comprehensive comparative assessments, identification of complementarities and contradictions between indicators and areas requiring further research and data improvement. An appropriate online portal would have to be found. One possible location of such a Portal for consideration by the relevant agencies could be FSIN mentioned above.

A major and coordinated effort is also recommended towards *enhancement of the empirical data base*, comprising all data relevant for measuring food insecurity and malnutrition. More specifically, the following steps towards improving the quality and the accessibility of the database are recommended:

- *Continue the current review of the food balance sheet data base in FAO*. This will play a major role in efforts to improve the accuracy and reliability of aggregate food consumption data. The FBS approach has the advantage of generating consumption data consistent with national agricultural statistics. However, currently this important variable is normally not derived from direct estimates, but calculated as a residual after accounting for all other components of the equation. As several of these, for example stock change and post-harvest losses, are subject to uncertain assumptions, the residual may actually accumulate a number of statistical errors. FAO's Statistics Division is aware of the underlying problems and seeking to improve the approach.

- *Reconcile data on food consumption derived from FBS and from household surveys.* In principle, mean levels of consumption per person derived, respectively, from national FBS on and from representative household surveys should be similar. It is hoped that where both types of estimates are available for the same countries, the proposed inventory of data may serve to identify major reasons for differences and entry points for resolution of those differences. Eventually, improved and representative household survey based estimates of food consumption could substitute for the use of FBS in more and more countries.
- *Enlarge the country coverage and frequency of household living standard and anthropometric surveys* so as to broaden the empirical base, including assessments of changes over time and comparisons between countries.
- *Harmonize the formats used for household living standard and anthropometric surveys* so as to facilitate comparisons over time and space.
- *Coordinate the sampling frames of household living standard and anthropometric survey,* or even merge both survey types, so as to facilitate comparison of different food insecurity and malnutrition indicators and enable important research on economic-nutrition-health linkages.
- Parallel to establishing an inventory and improving the data bases, a systematic *improvement of methods and assumptions* is recommended for all three principal indicator methods, making use of the latest findings in nutritional science and following up, *inter alia,* on the various suggestions made in this paper. Such an assessment should also include a careful assessment of the reliability and comparability of cut-offs currently used to determine inadequate access to calories, nutrients, as well as to determine nutritional status. Ongoing improvement efforts should be enhanced.
- More efforts should be made to use existing intergovernmental *platforms for advocacy and support of work with indicators of food insecurity and malnutrition.* The most prominent examples are the Committee on World Food Security (CFS) and the United Nations System Standing Committee on Nutrition (SCN).

Effective action towards such improvements requires political will of governments and governing bodies at regional and global levels, including the Committee on Word Food Security (CFS), which has just been reformed "with the aim to become the central United Nations political platform dealing with food security and nutrition". Accurate knowledge about who is food insecure, where they live and why they are food insecure and malnourished is a central precondition for effective action at all levels.

Improving metrics of food insecurity is also a contribution to the monitoring of the realization of human rights. As stated in the background document for the World Summit on Food Security in 2009, "where the existence of hunger and malnutrition results from negligence or ignorance by responsible policy-makers, it is also a violation of people's basic human right to adequate food and to a life in good health and dignity" (FAO, 2009).

It is encouraging to note that the weaknesses of the current metrics of food insecurity and malnutrition have been recognized by the agencies concerned, in particular the FAO, which is currently undertaking a fundamental review of the data and methods with the aim to improve them. We recommend that FAO interact closely with other relevant agencies, in particular WHO, UNICEF and World Bank, as well as with national governments to ensure broad support, consistency and mutual complementarities of the improvements.

With the current state of evidence it is safe to conclude that the available estimates of chronic hunger are inaccurate, but it is not possible to conclude whether the real number of undernourished is above or below the available estimates. It seems not even certain whether the direction of change has been correctly assessed for the different countries. Even with revised methods and more accurate data, estimates of food insecurity and malnutrition are bound to be subject to measurement errors and projections will remain uncertain. Thus the conclusion by the participants at the 2002 Symposium on Measurement and Assessment of Food Deprivation and Undernutrition remains valid that if the magnitudes of food insecurity are uncertain, at least the trends should be correctly captured. We believe that this is possible through improved data and methodological approaches. While in the short run, an improved FAO method may be used, we argue that, in the longer run, global measures of food insecurity and malnutrition should increasingly be based on household surveys that combine food consumption and anthropometric measurements.

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ANNEX B

BRIEF DESCRIPTION OF VARIOUS HOUSEHOLD SURVEYS CITED IN THE REPORT

	Demographic and Health Surveys (DHS)	**Living Standard Measurement Survey (LSMS)**	**Multiple Indicator Cluster Survey (MICS)**
Origin	Funded by USAID since 1984, implemented by ICF Macro, with large samples ranging from 5000-30000 households	The World Bank in the 1980s	UNICEF since 1995
Types of Data Collected	Prevalence of underweight children, education, under 5 mortality rates, maternal mortality rates, access to water and sanitation	Poverty, education, access to water and sanitation. Note, information on health status is not always measured	Under-five mortality, infant mortality, underweight prevalence, stunting prevalence, wasting prevalence, low birth weight, immunizations, as well as general indicators on reproductive health, child development, literacy and education and sexual behavior
Standard Methodology	Yes, with model questionnaires	Yes	Yes
Number of Countries Covered	84	Approximately 40	Varies from 50-95
Frequency of Data Collection at Country Level	Every five years	No regular pattern	Approximately every five years but expected to be done every 3 years from 2011

PART II

EXPLORING SUSTAINABLE SOLUTIONS FOR INCREASING GLOBAL FOOD SUPPLIES

INTRODUCTION

A second workshop, held in May 2011, was built on the discussions at the first workshop in which expert participants explored the availability and quality of metrics that helped us understand the concept of "sustainable food security." The 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.

The 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 to review the existing evidence regarding the magnitude of the problems and challenges and opportunities for their solutions. Subsequent sessions 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 the 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 following section includes a summary of the presentation by the committee chair, Per Pinstrup-Andersen, providing a contextual framework for the workshop. The first chapter in Part II 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 2 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 3 focuses on the political, economic, and institutional opportunities and barriers, and the final chapter discusses options for moving forward.

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.

CONTEXTUAL FRAMEWORK FOR WORKSHOP 2[1]

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 II I-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.

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

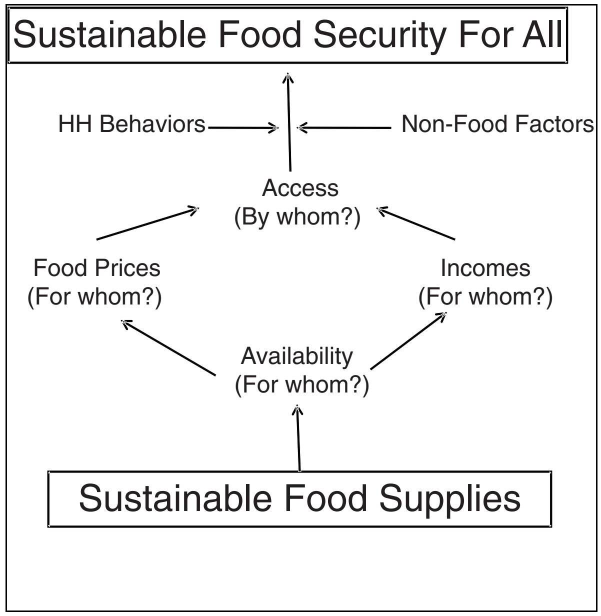

FIGURE II I-1 The Workshop Focus
SOURCE: Presentation by Per Pinstrup-Andersen, Cornell University, May 2, 2011.

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.

1

ACHIEVING SUSTAINABLE FOOD SECURITY: CHALLENGES AND OPPORTUNITIES

The first segment of the second 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[1]

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.

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

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, 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,[2] 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.[3] 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.

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[2] See, for example, B. Guha-Khasnobis, S. S. Acharya, and B. Davis (Eds.) 2007. Food Insecurity, Vulnerability and Human Rights Failure. UNU-Wider.

[3] 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.

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.[4]

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 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.[5]

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

[4] 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.

[5] According to sources cited by UNEP, even "57 percent 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").

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. 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[6]

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

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

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.[7] Consider crop yields, for example, as one seemingly straightforward and illustrative partial-factor productivity measure. Figure II 1-1 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.

[7] 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, 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."

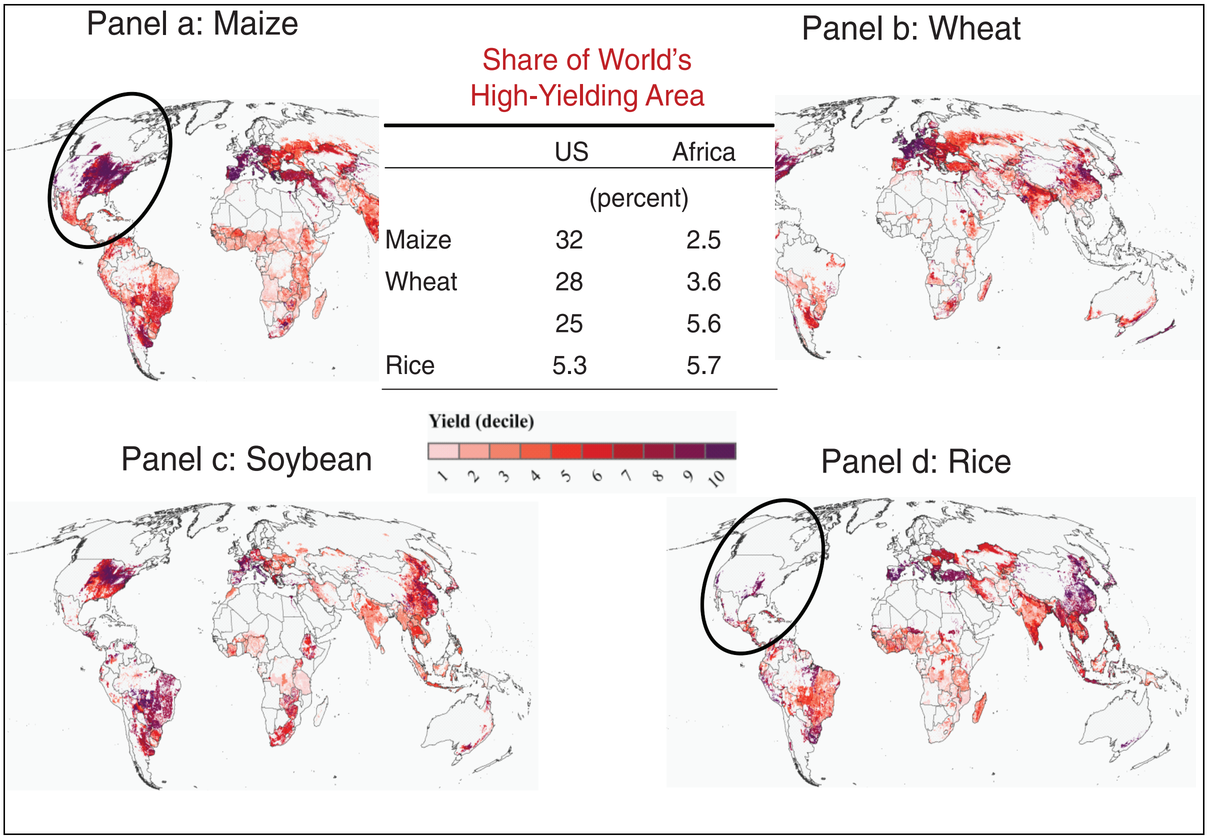

FIGURE II 1-1 Spatial Distribution of Crop Yields, 2000 (SPAM ver 3.0)
SOURCE: Presentation by Philip Pardey, University of Minnesota, May 2, 2011.

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.

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?[8]

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 settings as shown in Figure II 1-2.[9] They need to be reduced and closed as part of intensification. Reducing yield gaps will also raise the efficiency of water use.[10] 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.

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

[9] 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.

[10] Liters of water used to produce a unit of grain.

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 II 1-2 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 II 1-2 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.

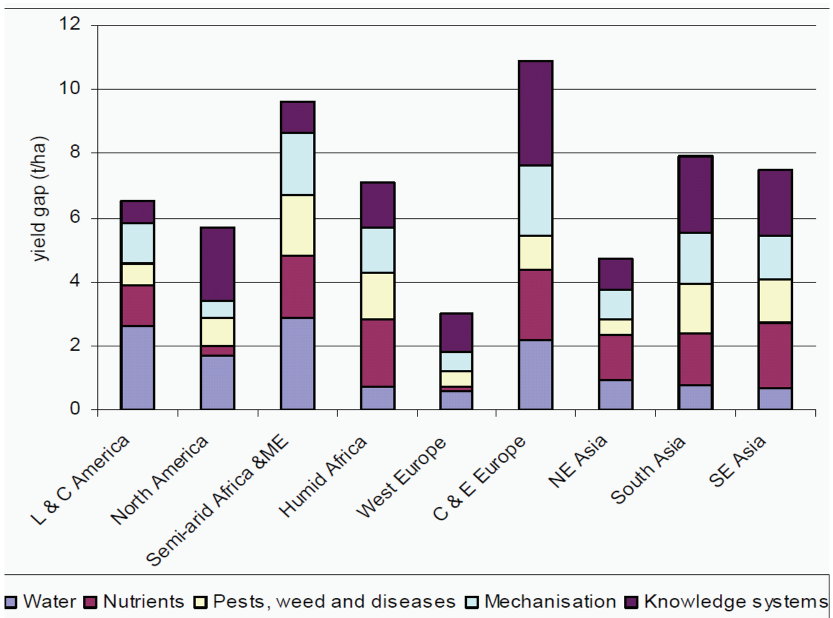

FIGURE II 1-2 Maize yield gap by region and contribution of five production constraints
SOURCE: Hengsdijk and Langeveld, 2009

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 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.[11] 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—c*an* 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 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.

[11] 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.

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[12]

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.

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

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, 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 II 1-3).

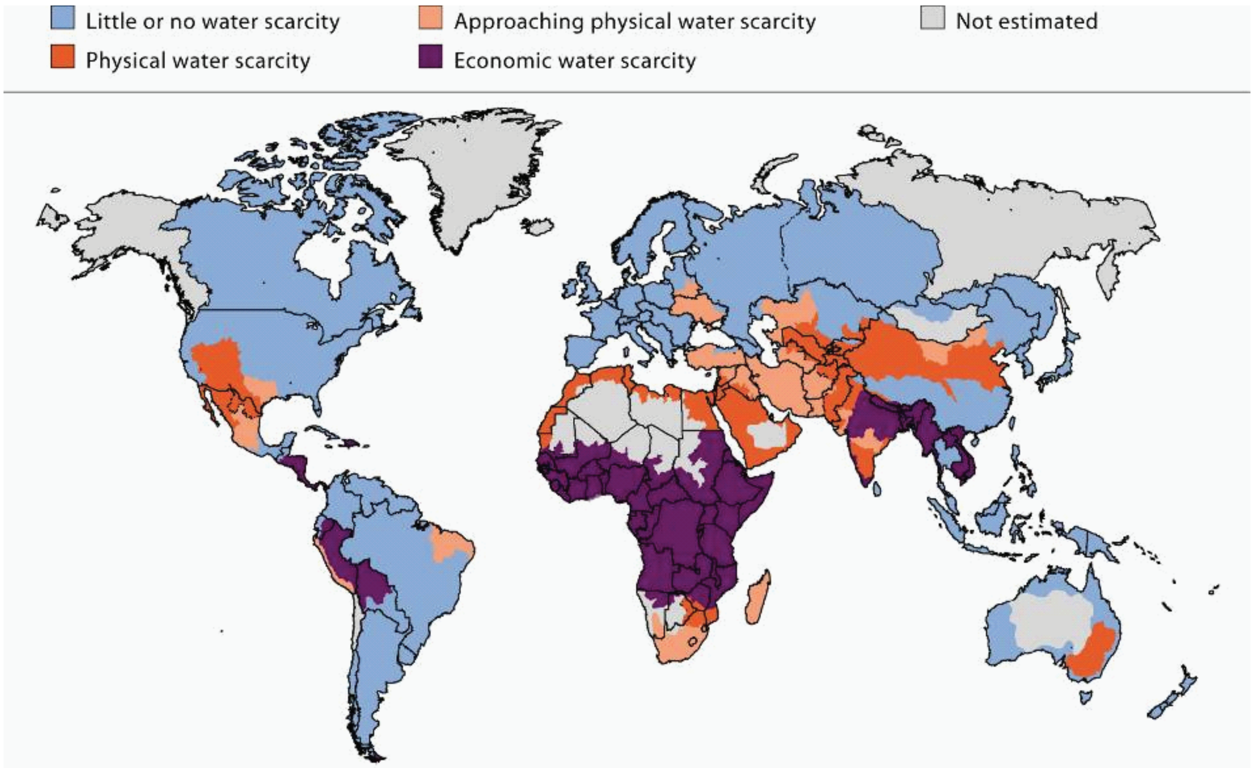

FIGURE II 1-3 Water Scarcity 2000.
NOTE: 1/3 of the world's population live in basins that have to deal with water scarcity.
SOURCE: Presentation by David Molden, IWMI, May 2, 2011.

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[13]

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

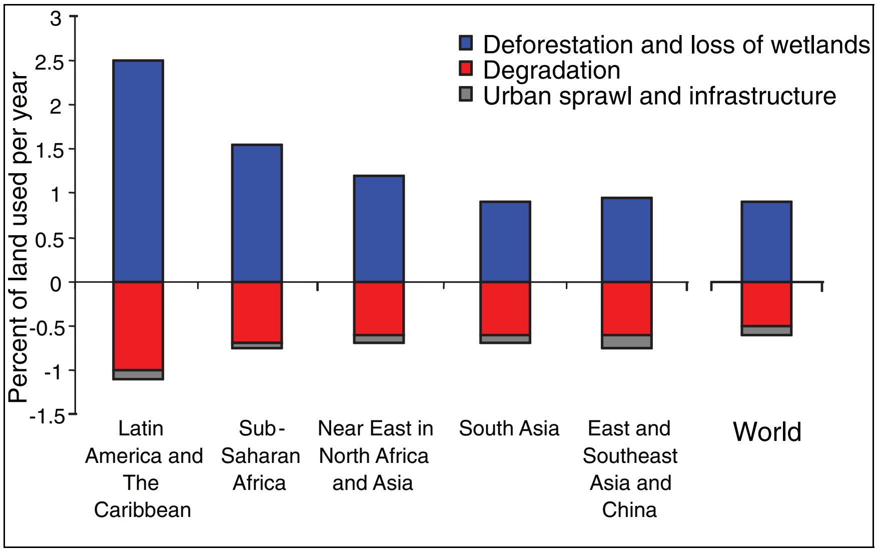

FIGURE II 1-4 Change in three classes of land use 1960-2000
SOURCE: Presentation by Paul Vlek, University of Bonn, May 2, 2011.

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[14]

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

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

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 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?[15]

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.

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.

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

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[16]

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.

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.

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

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 II 1-5).

FIGURE II 1-5
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)[17] 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

[17] 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).

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 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[18]

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

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

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 (Figures II 1-6; 1-7):

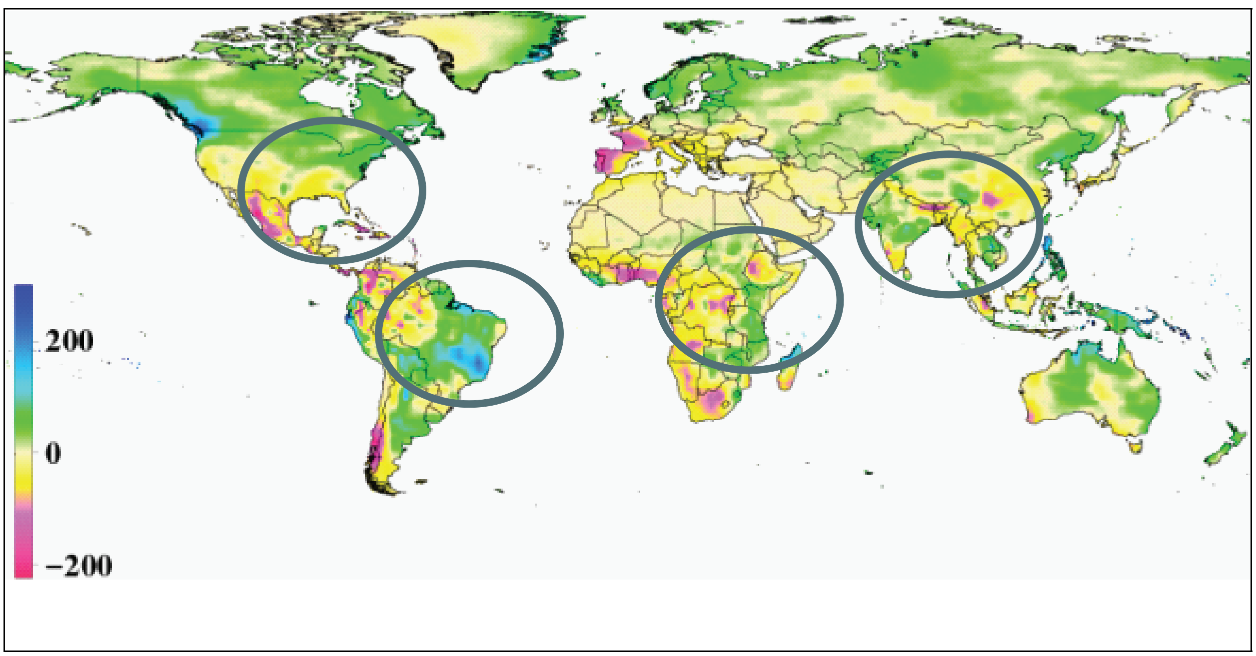

FIGURE II 1-6 Change in average annual precipitation, 2000-2050 CSIRO GCM, A1B (mm)
SOURCE: Presentation by Jerry Nelson, IFPRI, May 2, 2011.

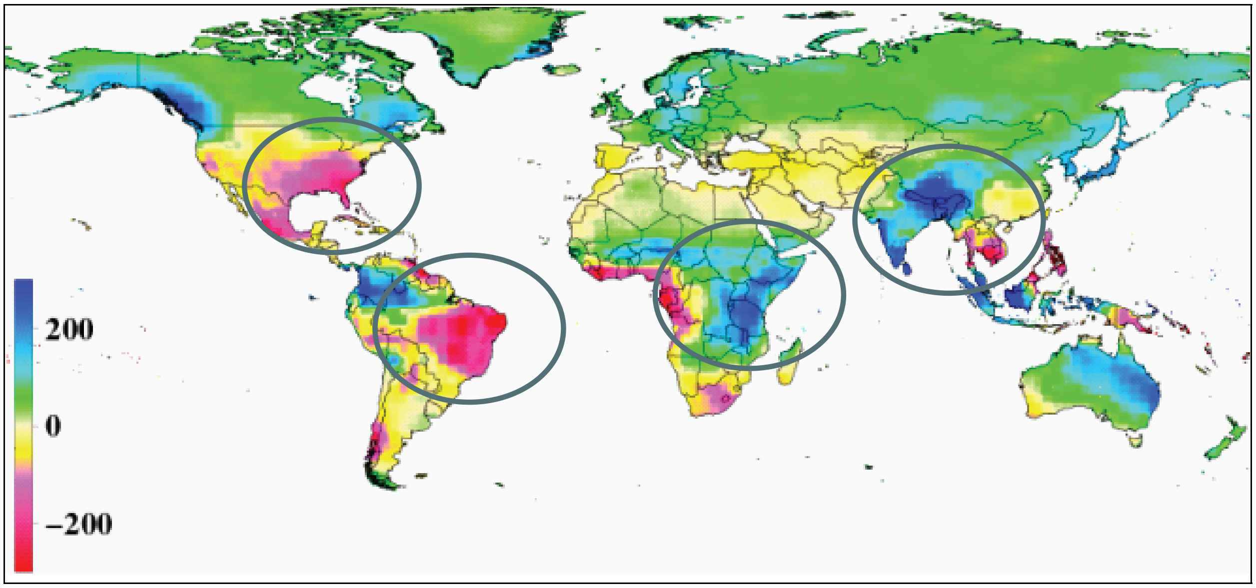

FIGURE II 1-7 Change in average annual precipitation, 2000-2050 MIROC GCM, A1B (mm)
SOURCE: Presentation by Jerry Nelson, IFPRI, May 2, 2011.

See the slide below (Figure II 1-8), which displays changes in maize yields with the MIROC model outputs.

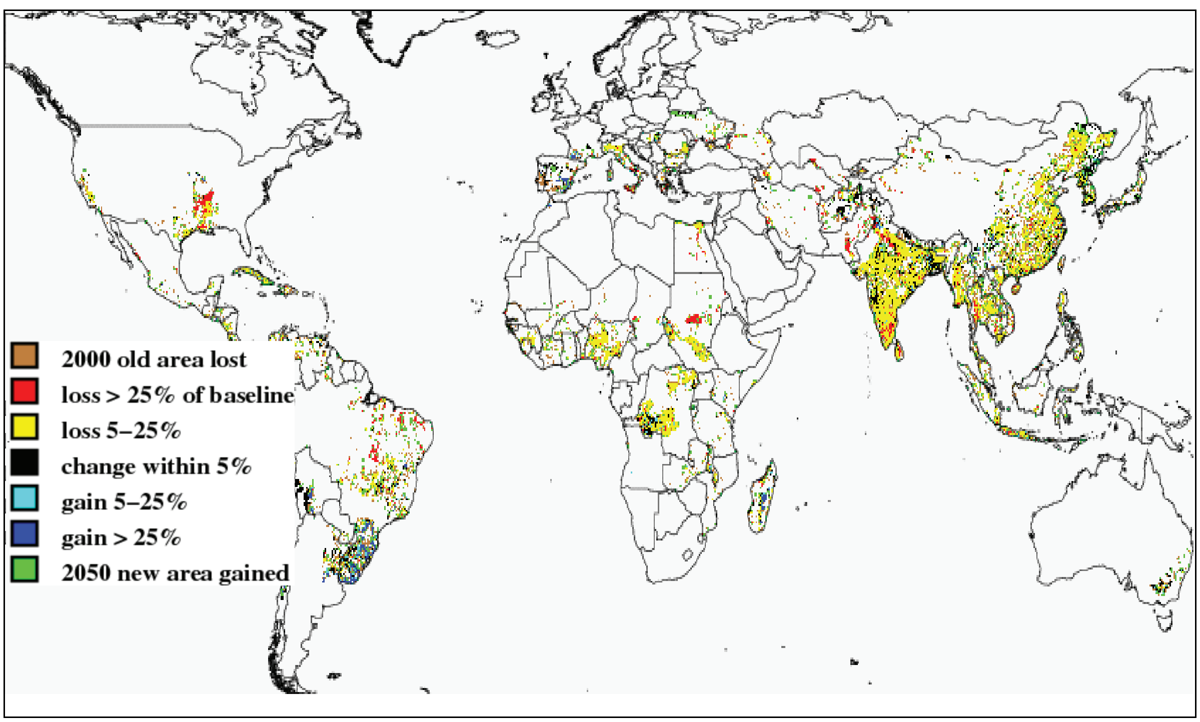

FIGURE II 1-8 Yield Effects, Irrigated Rice, MIROC A1B (percent change between 2000 and 2050 climate)
SOURCE: Presentation by Jerry Nelson, IFPRI, May 2, 2011.

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.

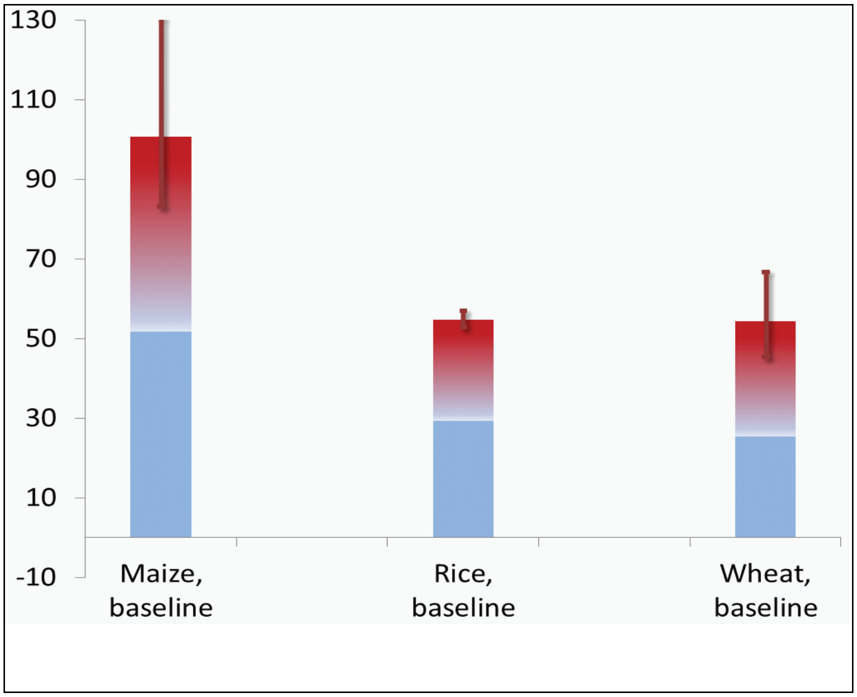

FIGURE 1-9 Climate Change Scenario Effects Differ (The vertical axis represents price increase [percent], 2010-2050, baseline economy and demography)
SOURCE: Presentation by Jerry Nelson, IFPRI, May 2, 2011.

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[19]

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.

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

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

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[20]).

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.

[20] See Agricultural Productivity and Natural Resource Endowments by Philip Pardey.

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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2

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[1]

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.

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

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 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 II 2-1). 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.

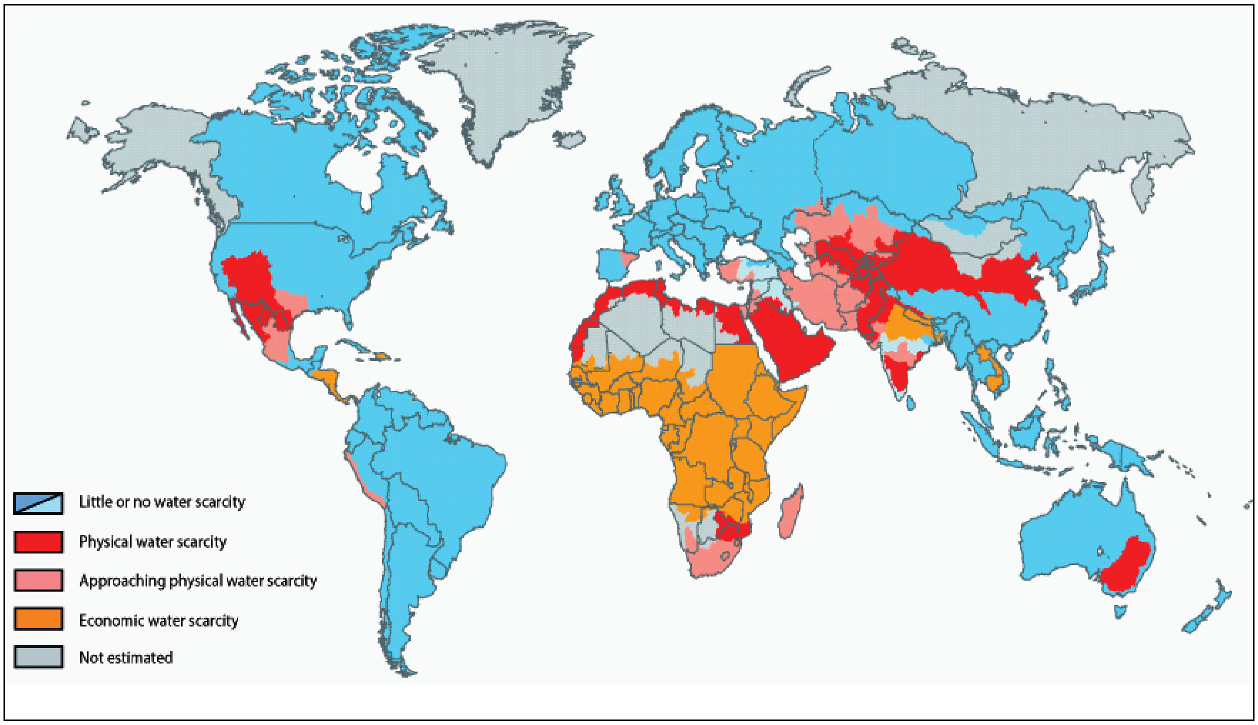

FIGURE II 2-1 Areas of physical and economic water scarcity.
SOURCE: Bushell 2011; IMWI Report, Insights from the Comprehensive Assessment of Water Management in Agriculture, 2006, p. 8.

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[2]

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

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

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 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[3]

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

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

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.

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[4]

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

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

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 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 United States 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[5]

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 II 2-2). However, there are a variety of mitigation factors that could significantly impact N fertilizer consumption, including extensive

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

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.

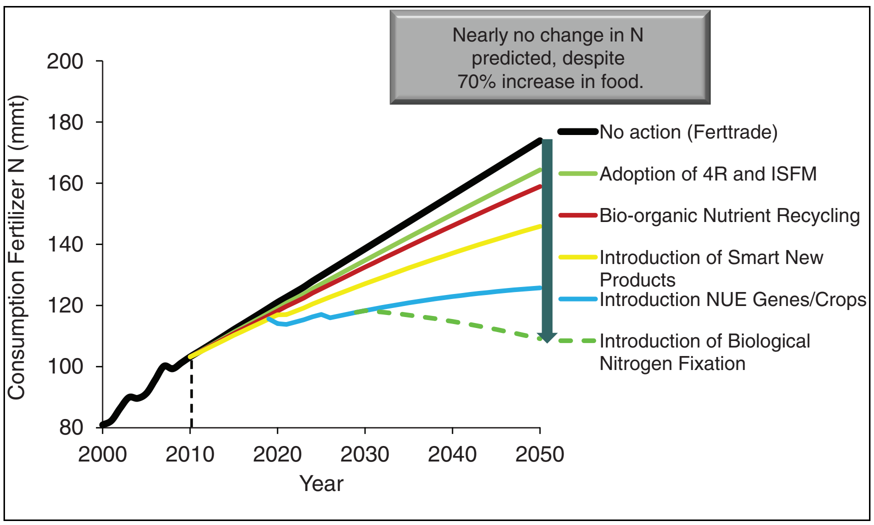

FIGURE II 2-2 IFDC FertTrade model
SOURCE: Presentation by Donald Crane, IFDC, May 3, 2011.

There is a high correlation between new technologies that improve N use efficiencies and energy conservation (Figure II 2-3). 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 II 2-3), 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.

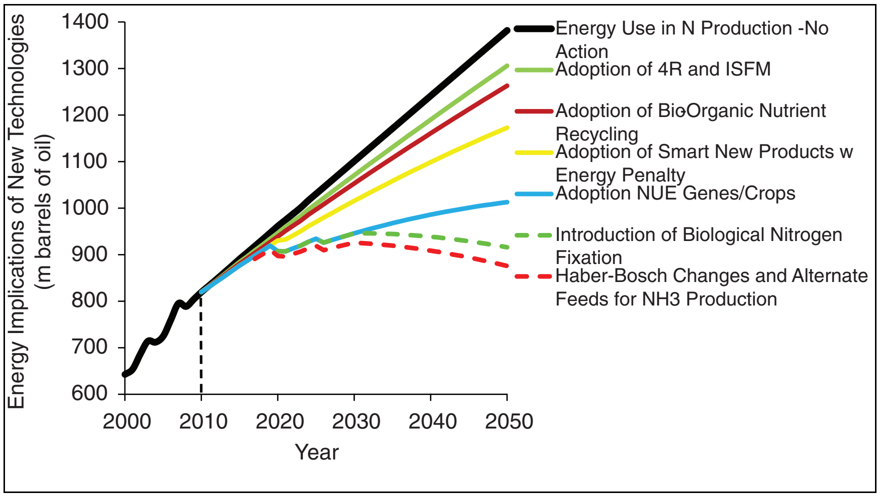

FIGURE II 2-3 N Energy Slide
SOURCE: Presentation by Donald Crane, IFDC, May 3, 2011.

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 II 2-4). 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 II 2-4 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.

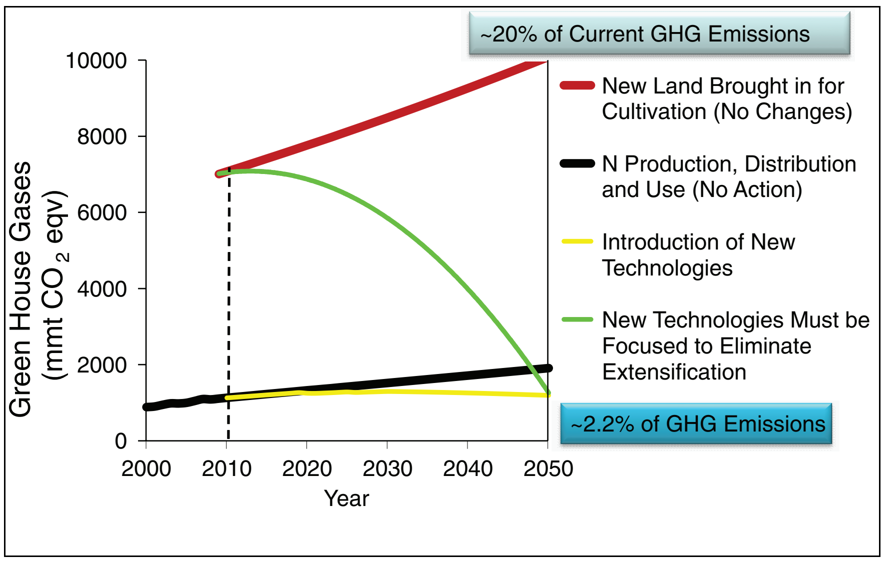

FIGURE II 2-4 N CO2 Slide
SOURCE: Presentation by Donald Crane, IFDC, May 3, 2011.

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[6]

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

[6] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Derek Byerlee (May 3, 2011). Much of this section is based on K. Deininger and D. Byerlee. 2011. Rising global interest in farmland: can it yield sustainable and equitable benefits? Washington, DC: The World Bank.

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 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[7]

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, 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.

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

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[8]; (6) effective insect control (disinfestation and protection against reinfestation); and (7) improved small scale food processing methods.

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

[8] 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.

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[9]

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 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.[10] 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.

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[9] The presentation is available at http://sites.nationalacademies.org/PGA/sustainability/foodsecurity/PGA_062564, presentation by Nancy McCarthy (May 3, 2011).
[10] 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.

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 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[11]

Laurian Unnevehr, Economic Research Service, U.S. Department of Agriculture[12]

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 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

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

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[13] 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

[13] 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.

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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3

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[1]

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.

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

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.

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. Table II 3-1 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 II 3-1 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[2]

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. 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-

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

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[3]

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

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

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, 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[4]

Dennis Treacy, Smithfield Foods

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

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

approach through a comprehensive environmental management system (EMS) based on the International Organization for Standardization (ISO) 14001 program.[5]

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 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.[6]

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

[5] 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.
[6] See Global Reporting Initiative. http://www.globalreporting.org/Home. Accessed on October 3, 2011.

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 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[7] 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 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:

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

- 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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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

WORKSHOP PARTICIPANTS

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Pat Basu
U.S. Department of Agriculture

Tim Benton
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SPEAKER BIOGRAPHICAL INFORMATION

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.

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.

MELINDA KIMBLE is a senior vice president of the United Nations Foundation, overseeing the Foundation's International Bioenergy Initiative. She joined the UN Foundation in May 2000. Prior to the Foundation, Ms. Kimble served as a state department foreign service officer, attaining the rank of minister-counselor. She served in policy-level positions in the Bureau of Economic and Business Affairs, overseeing multilateral development issues and debt policy; in the Bureau of Oceans, International Environment and Scientific Affairs (OES), leading environmental negotiations (e.g., Climate Change Conference, Kyoto, Japan, 1997). Her assignments abroad include Cote d'Ivoire, Egypt and Tunisia. She speaks French and Arabic and holds two master's degrees: Economics (University of Denver) and MPA (Harvard's Kennedy School of Government).

CAROL KRAMER-LEBLANC serves as Director of Sustainable Development at the U.S. Department of Agriculture. She is an agricultural economist with broad experience in the federal government, in academia, and with international organizations. Dr. Kramer-LeBlanc has worked for several years as an associate director at USDA's Economic Research Service in the natural resources area as well as served as Deputy Executive Director of the USDA Center for Nutrition Policy and Promotion and Director of the Foreign Agricultural Service' Research and Scientific Exchange Division.

DAVID LOBELL is an Assistant Professor at Stanford University in Environmental Earth System Science, and a Center Fellow in Stanford's Program on Food Security and the Environment. His research focuses on identifying opportunities to raise crop yields in major agricultural regions, with a particular emphasis on adaptation to climate change. Prior to his current appointment, Dr. Lobell was a Senior Research Scholar at FSE from 2008-2009 and a Lawrence Post-doctoral Fellow at Lawrence Livermore National Laboratory from 2005-2007. He received a PhD in Geological and Environmental Sciences from Stanford University in 2005, and a Sc.B. in Applied Mathematics, Magna Cum Laude from Brown University in 2000.

NANCY MCCARTHY is currently the President and Principle Analyst of LEAD Analytics, which focuses on providing research and consulting services in the area of law, economics and agriculture for development. Dr. McCarthy's major areas of expertise include: economic and institutional analyses of policies to manage climate change mitigation and adaptation in small-holder farming systems; risk management and coping mechanisms; sustainable land management; property rights and land tenure; and, economic and legal analyses of multilateral environmental agreements and intellectual property rights in the context of technology transfer. McCarthy has extensive field experience in fifteen sub-Saharan African countries, Mexico and Chile. Dr. McCarthy holds a PhD in Agriculture and Resource Economics from the University of California at Berkeley, and a JD Cum Laude from the George Mason University School of Law.

JEFFREY MILDER is an ecologist and land-use planner with fourteen years of experience in the field of conservation and sustainable development. He has worked with EcoAgriculture Partners since 2005, first as a Research Fellow associated with the Landscape Measures Initiative and payment for ecosystem services projects, and currently as Director of Strategic Planning and Research. Dr. Milder holds MSc and PhD degrees in Natural Resources from Cornell University and a BA in Earth Sciences from Harvard University. Most recently, he has conducted research on landscape-scale relations between agricultural management and biodiversity conservation in pasture-dominated landscapes of Central America. Prior to joining EcoAgriculture Partners, he founded and managed the community planning practice at Daylor Consulting Group, a design firm based in Massachusetts.

UZO MOKWUNYE currently serves as a Development Strategy Consultant. Dr. Mokwunye was a Professor and Head of the Department of Soil Science at the Ahmadu Bello University, Zaria, Nigeria. From 1996-2004, Dr. Mokwunye served as the Director of the United Nations University Institute for Natural Resources in Africa. He also served for 16 years as a staff member at the International Fertilizer Development Center (IFDC) and during this time, served for 7 years as the Director of IFDC-Africa. He also served as the Chair of the Governing Board of ICRISAT and the Chair of the CGIAR Committee of Center Board Chairs. He received his Bachelor of Science and Masters of Science at Ohio State University and his doctoral degree at the University of Illinois.

DAVID MOLDEN is Deputy Director General for Research at the International Water Management Institute (IWMI) with over 25 years in the field of water management. His passion for water grew from his experience helping villagers organize a drinking water well in Lesotho. He has a PhD from Colorado State University with specialties in groundwater hydrology and irrigation, and has since developed broader interests in integrating social, technical and environmental aspects of water management with work across Asia and Africa. Now in Sri Lanka with IWMI, he enjoys interdisciplinary and cross-cultural teamwork with IWMI and partners to solve local water problems. Recently David coordinated a global program involving over 700 participants to produce a Comprehensive Assessment of Water Management in Agriculture, with results documented in the publication Water for Food, Water for Life. The assessment examines trends, conditions, challenges and responses in water management for agriculture to enable effective investments and management decisions for enhancing food and environmental security. David received the 2009 award for CGIAR Outstanding Scientist.

JERRY NELSON is a senior research fellow at the International Food Policy Research Institute (IFPRI). He is an agricultural economist with over 30 years of professional and research experience in the areas of agriculture, policy analysis, land use and climate change. As co-leader of IFPRI's global change program, he is responsible for developing IFPRI's research in climate change modeling and spatially explicit assessments of potential adaptation and mitigation programs and policies. His previous professional activities includes leading the drivers of ecosystem services efforts of the Millennium Ecosystem Assessment, undertaking research that combines biophysical and socioeconomic data in quantitative, spatially-explicit modeling of the determinants of land use change, and understanding the effects of agricultural, trade and macroeconomic policies on agriculture and land use. Before joining IFPRI, Dr. Nelson was a professor in the Department of Agricultural and Consumer Economics, University of Illinois, Urbana-Champaign (1985-2008) and an Agricultural Development Council specialist at the University of the Philippines, Los Baños. He received his PhD from Stanford University in 1982.

PHILIP PARDEY (Committee Member) is Professor of Science and Technology Policy in the Department of Applied Economics and Director of the International Science and Technology Practice and Policy (InSTePP) center at the University of Minnesota. Previously he was a senior research fellow at the International Food Policy Research Institute, Washington, DC where he led the institute's Science and Technology Policy Program, and prior to 1994 at the International Service for National Agricultural Research in The Hague, Netherlands. He is a graduate of the University of Adelaide, Australia, and obtained a doctoral degree in agricultural and applied economics from the University of Minnesota. His research deals with the finance and conduct of R&D globally, methods for assessing the economic impacts of research, and the economic and policy (especially intellectual property) aspects of genetic resources and the biosciences. Dr. Pardey is a Fellow of the American Agricultural Economics Association and a Distinguished Fellow of the Australian Agricultural and Resource Economics Society.

ROBERT PAARLBERG is the Betty Freyhof Johnson '44 Professor of Political Science at Wellesley College, and a Visiting Professor of Government at Harvard University. He has consulted on African agriculture recently for IFPRI, USAID, COMESA, the Department of State, and the Bill and Melinda Gates Foundation. He is also a member of the Board of Agriculture and Natural Resources at the National Research Council and has published books on agricultural trade negotiations, environmentally sustainable farming, U.S. foreign economic policy, the reform of U.S. agricultural policy, and policies toward genetically modified crops. His latest book (2008) is titled "Starved for Science: How Biotechnology is Being Kept Out of Africa."

PRABHU PINGALI (NAS) is Head of Agricultural Policy and Statistics Division at the Bill and Melinda Gates Foundation. He was formerly an economist and Director of the Division of Agricultural and Development Economics at the UN Food and Agriculture Organization (FAO) from 2002-2007. He was the President of the International Association of Agricultural Economists (IAAE) from 2003-2006, Vice-President of the IAAE from 1997-2000, and chairman of the program committee for the 24th International Conference of Agricultural Economists. Dr. Pingali has over 25 years of experience in analyzing food, agriculture and development policy in Asia, Africa and Latin America. Before joining FAO, Dr. Pingali was Director of the Economics Program at the Economic Program at the International Maize and Wheat Improvement Center (CIMMYT) in Mexico, the International Rice Research Institute at Los Baños, Philippines, and the World Bank's Agriculture and Rural Development Department. He was a visiting scholar at Stanford University, Food Research Institute, and an Affiliate professor at the University of the Philippines at Los Baños. Dr. Pingali has authored nine books and over 90 referred journal articles and book chapters on food policy, technological change, productivity growth and resource management in the developing world. An Indian national, Dr. Pingali earned a Ph.D. in Economics from North Carolina State University in 1982.

AMIT ROY has been the president and chief executive officer of IFDC since 1992. Under his leadership, IFDC's programs have broadened to help create sustainable agricultural productivity around the world, alleviating hunger and poverty and ensuring global food security, environmental protection and economic growth. Dr. Roy joined IFDC in 1978 as a chemical engineer and special projects engineer. Dr. Roy was instrumental in organizing the Africa Fertilizer Summit in Abuja, Nigeria, in June 2006. In June 2008, he spoke before the Hunger Caucus of the U.S. House of Representatives about the role agro-inputs such as fertilizers and seeds have in providing long-term solutions to the recent food crisis and global food security. Dr. Roy is now leading IFDC in the development of the next generation of fertilizers, which will more effectively release nutrients when crops need them. He is also working to expand IFDC's successful fertilizer deep placement technology (FDP) from Bangladesh to Sub-Saharan Africa. Before coming to IFDC, Roy was a process engineer at the Georgia Institute of Technology in Atlanta. Dr. Roy earned a doctorate and a master's degree in chemical engineering from Georgia Tech. There, he served as a charter member of the Lions Club and was elected to the Graduate Student Senate. He received a bachelor's degree with honors in chemical engineering from the Indian Institute of Technology in Kharagpur, India.

EMMY SIMMONS (Committee Member) is currently an independent consultant on international development issues, with a focus on food, agriculture, and Africa. She serves on the boards of several organizations engaged in international agriculture and global development more broadly: the Partnership to Cut Hunger and Poverty in Africa, the International Livestock Research Institute (ILRI), the International Institute for Tropical Agriculture (IITA), the Washington chapter of the Society for International Development (SID), and the Africa Center for Health and Human Security at George Washington University. Ms. Simmons co-chairs the Roundtable on Science and Technology for Sustainability at the National Academies of Science and leads a Roundtable working group on Partnerships for Sustainability. She completed a career of nearly 30 years with the U.S. Agency for International Development (USAID) in 2005, having served since 2002 as the Assistant Administrator for Economic Growth, Agriculture, and Trade, a Presidentially-appointed, Senate-confirmed position. Prior to joining USAID, she worked in the Ministry of Planning and Economic Affairs in Monrovia, Liberia and taught and conducted research at Ahmadu Bello University in Zaria, Nigeria. She began her international career as a Peace Corps volunteer in the Philippines from 1962-64. She holds an M.S. degree in agricultural economics from Cornell University and a B.A. degree from the University of Wisconsin-Milwaukee.

MAXIMO TORERO is the Division Director of the Markets, Trade, and Institutions Division at the International Food Policy Research Institute, leader of the Global Research Program on Institutions and Infrastructure for Market Development and Director for Latin America. He has fifteen years of experience in applied research and in operational activities. In this capacity as director and research program leader, he directs the activities of an IFPRI unit that conducts research, with special emphasis on M&E of infrastructure and rural development interventions in urban and peri-urban areas through the use of randomized experimental design. Prior to joining IFPRI, he was a senior researcher and member of the executive committee at Group of Analysis for Development (GRADE). He received his Ph.D. from the University of California at Los Angeles, Department of Economics and held a postdoctoral fellow position at the UCLA

Institute for Social Science Research (ISSR). He is also a professor on leave at the Universidad del Pacífico, and Alexander von Humboldt Fellow at University of Bonn, Germany.

DENNIS TREACY (Committee and STS Roundtable Member) is Senior Vice President, Corporate Affairs and Chief Sustainability Officer, Smithfield Foods, Inc. As Senior Vice President, Mr. Treacy oversees and directs the company's sustainability and corporate affairs programs, including corporate communications and government relations. Since his arrival at Smithfield, he has helped enhance Smithfield's environmental, community and sustainability policies and initiatives to become a meat industry leader in Corporate Social Responsibility programs. Mr. Treacy has more than 30 years of experience in both the public and private sectors, having previously served as: Director, Virginia Department of Environmental Quality; Manager of Government Affairs, Browning-Ferris Industries; Assistant Attorney General of Natural Resources, Office of the Attorney General of Virginia; and Advisor for regulatory and policy issues at the West Virginia Department of Natural Resources and West Virginia Assistant Attorney General, Environmental and Energy Division. Mr. Treacy received his law degree from the Northwestern School of Law at Lewis and Clark College in Portland, Oregon, and his Bachelor's Degree in Fisheries and Wildlife from Virginia Polytechnic Institute and State University in Blacksburg, Virginia. Mr. Treacy is a member of the Virginia State Bar and West Virginia State Bar. He serves or has served as a member on dozens of statewide and national boards and commissions.

LAURIAN UNNEVEHR (Committee Member) is Director of the Food Economics Division, Economic Research Service (ERS), U.S. Department of Agriculture (USDA). Laurian has published over 60 journal articles and book chapters on topics in consumer demand and food policy as well as numerous other publications and outreach reports. She is recognized for original contributions in measuring the consumer benefits from agricultural research, the changing structure of U.S. food demand, and the cost-benefit trade-offs in food health regulation. With coauthors, she has received the American Agricultural Economics Association (AAEA) awards for Quality of Communication and for Publication of Enduring Quality, recognizing contributions in food policy and food demand. Laurian was inducted as a fellow of AAEA in July 2009. Prior to coming to ERS to lead the Food Economics Division, Laurian was on the faculty of the Department of Agricultural and Consumer Economics at the University of Illinois at Urbana-Champaign (UIUC) from 1985 to 2008. Laurian received her Ph.D. and M.A. from the Food Research Institute, Stanford University and her B.A. in economics from the University of California at Davis.

PAUL VLEK (Committee Member), a Soil Scientist, is Professor and Director of the Department of Ecology and Natural Resources of the Center for Development Research at the University of Bonn, a federally funded multidisciplinary research and teaching institute concerning sustainable development issues. Prior to accepting this post, he was a Professor and Director at the Institute of Agronomy in the Tropics at Georg-August University in Goettingen. Dr. Vlek is Editor-in-Chief of "Nutrient Cycling in Agroecosystems," and Editor of "Applied Botany" and "Basic and Applied Ecology." Dr. Vlek's research interests include the world's soil resources, agricultural use of land, and the evidence of ongoing degradation and desertification of the soil in many food-producing regions.

APPENDIX A

COMMITTEE BIOGRAPHICAL INFORMATION

PER PINSTRUP-ANDERSEN (Chair) 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.

MIKE BUSHELL is based at 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, head of external partnerships, and head of Jealott's Hill International Research Centre.

JASON CLAY 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.

BERT DRAKE 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.

WILLIAM JURY (NAS) is Distinguished Professor of Soil Physics & Soil Physicist, Emeritus at the University of California, Riverside. His principal research interests are: measurement and modeling of organic and inorganic chemical movement and reactions in field soils; development and testing of organic chemical screening models; characterization volatilization losses of organic compounds. At present, Dr. Jury is conducting research in field measurement and modeling of preferential flow of chemicals, chemical transport at low water content, unstable flow of water in soil, global water management, and sequential reuse of agricultural drainage water. He is a Fellow of the Soil Science Society of America, the American Association for the Advancement of Science, and the American Geophysical Union. In 1999 he was presented in Washington, DC with the USDA Secretary's Honor Award for Environmental Protection, and in 2000 was elected to the National Academy of Sciences. Recently, he has been identified by the Institute for Scientific Information as among the 100 most highly cited researchers in the world in both the fields of Engineering and Environment/Ecology. Dr. Jury earned his Ph.D. and MS in Physics from the University of Wisconsin and his BS in Physics from the University of Michigan.

PHILIP PARDEY is Professor of Science and Technology Policy in the Department of Applied Economics and Director of the International Science and Technology Practice and Policy (InSTePP) center at the University of Minnesota. Previously he was a senior research fellow at the International Food Policy Research Institute, Washington, DC where he led the institute's Science and Technology Policy Program, and prior to 1994 at the International Service for

National Agricultural Research in The Hague, Netherlands. He is a graduate of the University of Adelaide, Australia, and obtained a doctoral degree in agricultural and applied economics from the University of Minnesota. His research deals with the finance and conduct of R&D globally, methods for assessing the economic impacts of research, and the economic and policy (especially intellectual property) aspects of genetic resources and the biosciences. Dr. Pardey is a Fellow of the American Agricultural Economics Association and a Distinguished Fellow of the Australian Agricultural and Resource Economics Society.

JULES PRETTY is Professor of Environment and Society at the University of Essex, UK and designate Pro-Vice-Chancellor (from August 2010). His 16 books include *This Luminous Coast* (in press, 2011), *The Earth Only Endures* (2007), and *Agri-Culture* (2002). He is a Fellow of the Society of Biology and the Royal Society of Arts, former Deputy-Chair of the government's Advisory Committee on Releases to the Environment (ACRE), and has served on advisory committees for a number of government departments. He received an OBE in 2006 for services to sustainable agriculture, and an honorary degree from Ohio State University in 2009. His website is at www.julespretty.com.

MARIE RUEL is Director of the Poverty, Health, and Nutrition Division, International Food Policy Research Institute, a position she has held since 2004. She has worked for more than 20 years on issues related to policies and programs to alleviate poverty and child malnutrition in developing countries. She has published extensively in nutrition and epidemiology journals on topics such as maternal and child nutrition, agricultural strategies to improve diet quality and micronutrient nutrition with a focus on women's empowerment, urban livelihoods, food security and nutrition; in the past years, she also led a global process to develop universal indicators of child feeding practices with the World Health Organization. She has served on various international expert committees, such as the National Academy of Sciences, the International Zinc in Nutrition Consultative Group, and the Society for International Nutrition Research. Her current research focuses on the evaluation and strengthening of social protection programs and targeted nutrition interventions to foster human capital formation. She also coordinates a Platform on Agriculture and Health Research, a global initiative aimed at promoting and coordinating policy research on the 2-way linkages between agriculture and health to foster synergies between the two sectors and enhance program and policy and program effectiveness in reducing livelihood, food, health and nutrition insecurity. Before joining IFPRI in 1996, she was head of the Nutrition and Health Division of the Institute of Nutrition of Central America and Panama/Pan American Health Organization (INCAP/PAHO) in Guatemala, where she worked for six years. She earned her PhD in international nutrition at Cornell University.

EMMY SIMMONS is currently an independent consultant on international development issues, with a focus on food, agriculture, and Africa. She serves on the boards of several organizations engaged in international agriculture and global development more broadly: the Partnership to Cut Hunger and Poverty in Africa, the International Livestock Research Institute (ILRI), the International Institute for Tropical Agriculture (IITA), the Washington chapter of the Society for International Development (SID), and the Africa Center for Health and Human Security at George Washington University. Ms. Simmons co-chairs the Roundtable on Science and Technology for Sustainability at the National Academies of Science and leads a Roundtable working group on Partnerships for Sustainability. She completed a career of nearly 30 years with the U.S. Agency for International Development (USAID) in 2005, having served since 2002 as the Assistant Administrator for Economic Growth, Agriculture, and Trade, a Presidentially-appointed, Senate-confirmed position. Prior to joining USAID, she worked in the Ministry of Planning and Economic Affairs in Monrovia, Liberia and taught and conducted research at Ahmadu Bello University in Zaria, Nigeria. She began her international career as a Peace Corps volunteer in the Philippines from 1962-64. She holds an M.S. degree in agricultural economics from Cornell University and a B.A. degree from the University of Wisconsin-Milwaukee.

KOSTAS STAMOULIS is the Chief of Agricultural Sector in Economic Development Service (ESAE) and Agricultural and Development Economics Division (ESA), Food and Agriculture Organization of the United Nations (FAO). Dr. Stamoulis's major focuses include: the potential of the rural economy for growth and poverty reduction; changes in food systems and commercialization with effects on smallholders, rural development and rural poverty; analysis of trends in rural development analysis and practice; seed markets as a means of promoting the sustainable utilization of crop genetic resources; introducing food security objectives and policies in Poverty Reduction Strategy Papers; and behavioral economics and development policy. His field activities include: introducing food security and agriculture-related objectives and strategies in the Poverty Reduction Strategy Processes in Kenya, Mozambique, Tanzania, Bhutan, Laos and Cambodia; and constraints facing small farmers in supply supermarkets in Honduras and El Salvador. Dr. Stamoulis holds a Ph.D. in Agricultural Economics from the University of California, Berkeley and MS in Agricultural Economics from the University of Georgia.

DENNIS TREACY is Senior Vice President, Corporate Affairs and Chief Sustainability Officer, Smithfield Foods, Inc. As Senior Vice President, Mr. Treacy oversees and directs the company's sustainability and corporate affairs programs, including corporate communications and government relations. Since his arrival at Smithfield, he has helped enhance Smithfield's environmental, community and sustainability policies and initiatives to become a meat industry leader in Corporate Social Responsibility programs. Mr. Treacy has more than 30 years of experience in both the public and private sectors, having previously served as: Director, Virginia Department of Environmental Quality; Manager of Government Affairs, Browning-Ferris Industries; Assistant Attorney General of Natural Resources, Office of the Attorney General of Virginia; and Advisor for regulatory and policy issues at the West Virginia Department of Natural Resources and West Virginia Assistant Attorney General, Environmental and Energy Division. Mr. Treacy received his law degree from the Northwestern School of Law at Lewis and Clark College in Portland, Oregon, and his Bachelor's Degree in Fisheries and Wildlife from Virginia Polytechnic Institute and State University in Blacksburg, Virginia. Mr. Treacy is a member of the Virginia State Bar and West Virginia State Bar. He serves or has served as a member on dozens of statewide and national boards and commissions.

LAURIAN UNNEVEHR is Director of the Food Economics Division, Economic Research Service (ERS), U.S. Department of Agriculture (USDA). Laurian has published over 60 journal articles and book chapters on topics in consumer demand and food policy as well as numerous other publications and outreach reports. She is recognized for original contributions in measuring the consumer benefits from agricultural research, the changing structure of U.S. food demand, and the cost-benefit trade-offs in food health regulation. With coauthors, she has received the

American Agricultural Economics Association (AAEA) awards for Quality of Communication and for Publication of Enduring Quality, recognizing contributions in food policy and food demand. Laurian was inducted as a fellow of AAEA in July 2009. Prior to coming to ERS to lead the Food Economics Division, Laurian was on the faculty of the Department of Agricultural and Consumer Economics at the University of Illinois at Urbana-Champaign (UIUC) from 1985 to 2008. Laurian received her Ph.D. and M.A. from the Food Research Institute, Stanford University and her B.A. in economics from the University of California at Davis.

PAUL VLEK, a Soil Scientist, is Professor and Director of the Department of Ecology and Natural Resources of the Center for Development Research at the University of Bonn, a federally funded multidisciplinary research and teaching institute concerning sustainable development issues. Prior to accepting this post, he was a Professor and Director at the Institute of Agronomy in the Tropics at Georg-August University in Goettingen. Dr. Vlek is Editor-in-Chief of "Nutrient Cycling in Agroecosystems," and Editor of "Applied Botany" and "Basic and Applied Ecology." Dr. Vlek's research interests include the world's soil resources, agricultural use of land, and the evidence of ongoing degradation and desertification of the soil in many food-producing regions.

APPENDIX B

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.

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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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