

Opportunities and Solutions for Sustainable Food Production

BACKGROUND RESEARCH PAPER

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This paper reflects the views of the author and does not represent the views of the Panel.

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Background paper for the
High-Level Panel of Eminent Persons on the Post-2015 Development Agenda

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Summary

The demand for food will greatly increase due to rising incomes and an additional two or three billion people to feed. Agriculture needs to change to meet that demand. Investing in agriculture is also one of the most effective strategies for achieving critical post-2015 development goals related to poverty and hunger, nutrition and health, education, economic and social growth, peace and security, and preserving the world's environment.

This paper expands on a previously submitted briefing paper on *Profile of Hunger and Food Insecurity* (October 2012), which provided a macro view of the food production challenges.¹ Here, we propose key goals of a post-2015 framework for sustainable increases in food production and we provide examples of available solutions. We believe that it is possible to eradicate extreme poverty, hunger and undernourishment by 2030 and sustain food security without irreversibly damaging the world's natural resources, even in a time of climatic changes and extremes. To achieve that, rising food yields must be decoupled from unsustainable utilization of water, energy, fertilizers, chemicals and land. We call for a multi-faceted agro-ecological intensification of food production to

- Increase productivity by at least 70% on existing crop and pasture land;
- Make farming an attractive economic development opportunity for people living in rural areas, particularly smallholder farmers and small to medium entrepreneurs;
- Preserve the environment through ultimately stopping the expansion of agriculture into sensitive ecosystems, lowering resource intensity, and sound use of inputs; and

¹ Future reports on Agriculture by the SDSN can be found on our website, http://unsdsn.org/thematicgroups/tg7/tg7_resources.

- Reduce food waste.

Many of the solutions for that exist or could, with wise investments, become available in the next 10-20 years. Early action is important, but we also need political will and better mechanisms for long-term thinking and action, particularly more support for public R&D and human resources development to foster innovation and behavior change.

That was then, this is now

Agriculture is the world's largest use of land, occupying about 38% of the Earth's terrestrial surface ¹. The agricultural community has had tremendous successes in massively increasing world food production over the past five decades and making food more affordable for the majority of the world's population, despite a doubling in population. Global production of main grains has roughly tripled since 1960, with corresponding decreases in price in most markets ². The Green Revolution was a spectacular success credited with saving millions of lives and millions of hectares of natural ecosystems.

The transformation of agriculture over the past 50 years to what we now know as “modern” agriculture took advantage of inexpensive fossil fuels to raise agricultural productivity in many world regions. Technological innovations, investments in infrastructure and supporting policies including subsidies were effective in some regions but others have been left behind, particularly Sub-Saharan Africa ³. Yield trends in the past 50 years and current yield gaps vary widely among and within countries ^{4,5}.

Contemporary food systems have also exerted undesirable pressure on terrestrial and aquatic ecosystems and they are failing to provide adequate nutrition to billions of people. An estimated 870 million people still lack sufficient caloric intake, while a billion or more suffer from micronutrient deficiencies. Another 1.4 billion suffer from overweight or obesity. Progress in reducing poverty and hunger has slowed down in recent years ⁶.

Food prices began to rise slowly around 2004 and have fluctuated much since 2007, highlighting the vulnerability of global food supplies and re-vitalizing interest in farming and related issues after a long period of neglect. Global food demand will continue to increase for at least another 50 years – against a backdrop of growing competition for land, water, labor and energy and under threat from climate change. FAO projects that feeding a world population of about 9 billion people in 2050 would require raising overall food production by at least 70 % ⁷.

Depending on actual demographic trends, crop production may even have to double within that period to also keep pace with dietary changes and increasing bioenergy use of crops ^{1,8}. A fast rising middle class in transition countries will exacerbate the demand for energy-intensive food categories beyond levels not seen before. On the supply side, concerns include climate variability and change, rising energy prices, conflicts over land and water, soil degradation, and out-migration of labor from rural areas.

Agriculture faces indeed an intimidating set of unprecedented challenges and risks. As we face these challenges for the world's current and future inhabitants, we must call for a new approach that ensures success and sustainability under this new set of constraints. We now need a “post-modern” agriculture that draws more effectively on production ecology principles to improve the

productivity and efficiency of agriculture while reducing negative environmental impacts. While modern agriculture has used fossil fuel-based inputs to achieve an optimized uniformity in many areas, post-modern agriculture can benefit from cheap information to bring about agro-ecological intensification based on optimized complexity.

The state of agriculture and food production, the future challenges faced and the potential solutions have all been discussed in numerous recent reports¹⁻²¹. Although different stakeholders may disagree on the specific agricultural development pathways or the technology solutions to prioritize, a consensus is emerging that

- We must eradicate poverty, hunger and malnutrition in our generation.
- Agricultural growth, particularly in staple crops, is among the best routes for achieving these and other development goals in developing countries.
- The previous model of resource-intensive agriculture cannot be continued in a world with finite resources provided by the Earth's land, oceans, and atmosphere.
- The world's agriculture and food systems must become more productive, more resource-efficient, more resilient, and less wasteful.
- Farming must become more attractive and profitable for all who are involved in the different value chains, but particularly also for the hundreds of millions of small-scale farmers and small to medium-size entrepreneurs in the developing world.
- We need to ensure equity in terms of access to inputs and markets in all parts of the world to help smallholders escape from poverty and resource depletion traps.
- Social support programs are needed to benefit women and the most vulnerable.

- We must transform agriculture in a broad but also multi-faceted manner across multiple agricultural subsectors to respond to the diversity of farmers' environments, objectives, constraints and incentives.
- There are multiple technology choices and paths for improving productivity, economic and environmental performance of agriculture.
- Meaningful, sustained change requires more public investments in agriculture, particularly investments in infrastructure, research and human resources development to improve performance and ensure equitable distribution of benefits.

Post-2015 Goals for Sustainable Agriculture and Food Production

Food security, nutrition and health goals

- Increase the world's real food supply by 70-100% by 2050 through increasing agricultural productivity on existing land, minimizing the use of food crops for bioenergy, and reducing food waste.
- Improve the distribution and access of food.
- Eradicate hunger by 2030 (caloric insufficiency).
- Eradicate malnutrition by 2030 (nutrient insufficiency).
- Make food production systems more resilient.
- Shift diets and produce healthier food.

Economic and social development goals

- Keep food affordable for the poor; eradicate extreme poverty by 2030.
- Increase the income of rural households.

- Make agriculture an attractive economic development opportunity for people living in rural areas – slow down outmigration and urbanization.

Environmental development goals

- Slow down and ultimately stop the expansion of agriculture into sensitive natural ecosystems.
- Increase the efficiency of natural resources consumed in agriculture (water, energy, fertilizer, etc.) to lower the global warming potential of agriculture and to reduce water and air pollution.
- Stop unsustainable withdrawal of water resources, soil degradation, and soil nutrient depletion.
- Protect wildlife, biodiversity and other ecosystem services in agricultural landscapes.

Achieving these goals will require changing the behavior of all actors involved in the agriculture and food sector, from the consumer to the farmer. Many interventions are needed, but not all can be done at once. Changing diets towards more healthy, less resource-intensive food is likely to be a slow, uneven process. On the supply side, the most critical issue is to increase production on existing crop land by closing yield gaps and, where possible, diversifying and increasing the number of crops grown per year, as well as reducing post-harvest losses. That is a prerequisite for being able to stop agricultural expansion into natural environments.

We need to move away from ideological or emotional battles over whether it is right or wrong to eat meat or whether agriculture should be “conventional”, “GM”, or “organic”. All of those will

be needed. We need to concentrate our efforts on actionable solutions that are science-based and tailored to the local situations and needs. To enable farmers to adapt their systems to new opportunities and constraints, we need to equip them with a suite of technology options, the right knowledge and information, and mechanisms to gain fair access to markets and new technologies.

Agro-ecological intensification of food production

Addressing the new Triple Green Revolution challenge requires the systematic application of science-based, agro-ecological principles to enable an *agro-ecological intensification* for more precise farming in small and large farms anywhere in the world ^{22,23}. Depending on the context, improved performance may mean any or all of the following: increased productivity and profitability, enhanced use of local resources, maximized returns from external inputs, improved stability and diversity of yields, reduced greenhouse gas emissions, enhanced ecological resilience and environmental service provision.

There are still significant yield gaps in some world regions that can be exploited through simple interventions such as better seed, nutrients, and water management ⁴. However, it is generally necessary to move towards more sophisticated, more knowledge-intensive forms of agriculture – and provide the technologies and incentives that make it viable for farmers to adopt and adapt them. In crop production, agro-ecological intensification primarily implies to implement good agronomic management principles in a local context, including:

- Profitable and sustainable crop rotations

- Choosing quality seed of a well-adapted high-yielding variety or hybrid that also meets market demands
- Planting at the right time to maximize the attainable yield by capturing light, water and nutrients
- Maximize the capture and efficient utilization of available water
- Integrated soil and nutrient management, including conservation agriculture, balanced and more efficient use of fertilizers, as well as utilization of available biological and organic sources
- Integrated pest management, including the use of functional biodiversity, biological control and the judicious use of pesticides
- Harvesting at the right time
- Optimize recycling and use of biomass and agricultural by-products
- Where suitable, enhance crop-tree-livestock interactions

There are many examples that have demonstrated how productive and resource-efficient agriculture can indeed be if it is done in that manner. The important point is that this can all be done in farm enterprises of different sizes and degrees of market integration. It will particularly benefit resource-limited, small farm enterprises. Critical to success is the use of modern science and technology combined with local knowledge.

The specific policies and interventions for implementing such an agro-ecological intensification depend on the social and biophysical contexts in which farmers operate. Different solutions are required for large farms with good market access and high input use, small farms with good

market access and high input use, or small farms with low market access and low input use.

Strategies for agro-ecological intensification must provide viable options both for farms that can produce substantial surplus and for small farms that support billions of resource-constrained people.

Farmers who are blessed with large landholdings and other capital, good market access and support systems, and the capacity to use farm inputs like irrigation, purchased fertilizer and other agricultural inputs can produce the large surpluses that keep food prices low. Such farmers, like their counterparts with smaller farms, may be vulnerable to rising energy costs insofar as irrigation, fertilizer and transport to market are dependent on fossil fuels. Technologies that allow them to increase yields and the efficiency of cost-intensive inputs (or substitute them partially) will increase their profitability and reduce the damage done to the environment.

Globally, there are over half a billion small farms and they produce much of the world's food by working two hectares or less, including much of the food they consume. Smallholder farmers are often disadvantaged in accessing markets and rely substantially on self-provisioning. It is difficult for a farming family to make a much better living from growing crops or raising a few animals on a one or two acre plot with low inputs and primitive technologies. Even if those systems can be improved somewhat through low-input technologies, this is probably not a sustainable vision for the future. Instead, we should aim to re-invent farming as an attractive local business opportunity for smallholder farmers and their families and also create opportunities for entrepreneurs in the value chain, thus relying less on government handouts or foreign aid.

Public, civil society and private sector must work together to support this agro-ecological intensification by implementing the following processes:

- *Diagnosis*: Understand the context in which an effort or intervention will be implemented and its links to global agro-ecological knowledge.
- *Contextualized principles*: Identify the right economic, social and ecological principles of relevance to farmers' needs.
- *Getting it right locally*: Empower local communities to improve the performance of the farming system based on agro-ecological principles and local preferences.
- *Scaling and support*: Expand the scope of the effort or intervention (in terms of numbers of people involved and the size of the territory) and create the necessary value chains, services, support systems and self-sustained business models.
- *Evidence*: Monitor and document the performance, learn to enrich the local and global knowledge base to influence policies that will support further implementation.

Utilizing agro-ecological principles in agriculture does not mean that we should blindly copy natural ecosystems that have not been optimized for food, feed, fiber or bioenergy production. The generic principles of agro-ecological intensification can be applied to any agricultural system and its associated value chain, no matter whether that is conventional, organic or some other form of agriculture.

Available solutions for early action

Many solutions must add up to making a huge difference, but some new technologies can indeed trigger transformative changes. Generally speaking, practical solutions for transforming world agriculture need to address innovation, markets, people, and political leadership ¹².

Early solutions need to focus on critical areas where improvement in productivity and environmental performance can be made relatively quickly. Crop yield gaps ⁴ or livestock productivity gaps, for example, vary widely worldwide and are particularly large in Sub-Saharan Africa and some other developing countries regions. On the other hand, opportunities for improving the environmental performance of agriculture are largest in countries where there is already excess use of inputs such as nitrogen fertilizers and pesticides, for example in China ²⁴.

The key interventions need to take place at the farm level. Farming is a complex and risky business. Its success heavily depends on the size and quality of land owned or rented, weather, markets, knowledge, access to inputs, support services and capital, infrastructure and time made available to tend to fields or animals. Hence, solutions need to be flexible in terms of being able to tailor them to local needs and production situations and scaling them up and out. That requires offering a suite of new technologies and support systems, which must be provided by different sectors in a complementary mode.

The domestic private sector – composed of millions of farmers and other local business – is by far the biggest investor in agriculture ²⁵. Therefore, farmers - small farmers and entrepreneurs in

particular - must be central to any investment and policy strategy that enables the development and widespread adoption of new solutions^{10,18}. The goals for sustainable agriculture and food production can only be achieved if domestic governments and the international community create an environment that enhances more economically, socially and environmentally sustainable private investment in agriculture.

Below we provide some specific examples for early-action solutions, i.e., interventions that should be of high priority for at least the coming 10 years:

- Close yield gaps and reduce yield variability through improved crop varieties with tolerance to drought, salinity, submergence, high temperatures, diseases and insect pests (enhanced conventional breeding and biotechnology).
- Close yield and efficiency gaps through an agronomic revolution: more precise crop management through locally adapted, affordable new technologies and access to information.
- Energy for all in agriculture: Implement a small- to medium-scale mechanization revolution in areas that still rely on labor-intensive agriculture. Create the necessary local services and support systems for that. This is essential for more timely and more precise agronomic management.
- Smart technologies for increasing the efficiency of energy, water and nutrients: conservation agriculture, site-specific nutrient management, low-cost drip irrigation and other water-saving irrigation technologies.

- Provide solar and wind power to rural areas for supporting irrigation, small enterprises, and rural households.
- Harvest and postharvest technologies that save labor, reduce grain losses and improve product quality: combine harvest, drying and hermetic storage.
- Take advantage of cheap information (mobile/smart phones, internet, social media, videos, remote sensing, soil and weather data, etc.) to provide digital agriculture solutions for farmers (access to information, knowledge, inputs and markets).
- Invest in agricultural infrastructure to enable intensification and diversification of agriculture through access to inputs, people, knowledge, markets, education, health services: roads, irrigation, electricity, internet, storage, processing. Create a decent living environment for people to stay in rural areas.
- New business models for smallholder farming: test, promote, and support new farming enterprises and integrated value chains that link farmers to the market. Connect farmers with rapidly growing domestic and export markets and make them direct beneficiaries of competitive food systems. Foster new forms of small-medium enterprises at all levels of the value chain, from food production to processing and marketing. Create new business opportunities for women.
- Support the growth of rural agribusiness hubs that provide the full range of inputs and services to farmers and their families, and treat them with respect.
- Conduct concrete larger-scale pilot studies (~100,000 ha) to implement structural changes towards new models of smallholder farming. Learn in practice and show what can be achieved over short time through a well-targeted integrated agronomy, digital

agriculture, value chain and business development approach following agro-ecological intensification principles.

- Community agriculture professionals: speed up last-mile delivery of new technologies and knowledge through innovative programs that create a generation of proud agricultural professionals who can provide actionable, local advice to farmers as respected customers. Create incentives and self-sustained business models for that. Make full use of modern ICT tools for this purpose.
- Move from poorly targeted subsidies and free handouts (seed, fertilizer, pesticides, machinery) towards providing low-cost financing and technical support as key incentives for local businesses and farmers to adopt proven, science-based technologies that increase productivity and efficiency, and thus also conserve natural resources.
- Provide credit to agri-business working in the developing world and weather-indexed insurance to small holder farmers to help manage production risks and give farmers the confidence to invest more in agriculture production.
- Policy liberalization in the agribusiness and food sectors to remove current constraints and wrong incentives that limit establishing a more competitive market: trade barriers and tariffs, subsidies.
- Stop chopping down forests or draining natural wetlands with high levels of biodiversity or high risk of release of greenhouse gases (carbon) or other undesirable consequences.
- Promote evidence-based win-win crop management technologies that enable farmers to participate in carbon trading (CDM – Clean Development Mechanisms).

- Carefully target support and tax breaks to stimulate more vibrant private sector R&D. Strengthen IP rights and provide incentives for more private sector investment in R&D, including the necessary policy framework (IP laws, seed movement, legal and operational framework for faster approval of new products).
- Create new knowledge-sharing platforms for south-south learning and cooperation.

Futuristic solutions

Foresight is needed to avoid that 20 or 30 years from now the world runs into another food crisis. Hence, in addition to investing in early solutions or technologies that are likely to become available in the next 5-10 years, strategic investments in groundbreaking research are needed to potentially make quantum leaps in the performance of agricultural systems beyond that.

Examples for that may include:

- Unraveling gene functions by sequencing and phenotyping the world's collections of crop and animal genetic resources, and using that know-how in conventional and biotechnology applications for accelerating next generation crop and animal breeding. The revolutions in biological sciences technology and computing have put this exciting opportunity at our fingertips now. Yet, massive investments are needed for that, also for handling the huge amounts of data to be generated. The potential returns on such investments are huge and broad, with particular benefits accruing in small farms worldwide.
- Re-engineering crop photosynthesis to increase yields and make crops more resource-efficient. Introducing C4-photosynthesis into a C3 crop such as rice could produce 30-

50% more yield for the same amount of sunshine, water and nitrogen. No other known intervention exists that could potentially achieve the same.

- Genetic improvements to increase the nitrogen use efficiency in non-leguminous crops, including engineering mechanism for fixing atmospheric N_2 into such crop species. Nitrogen fertilizers account for 1/3 of the total annual creation of reactive nitrogen compounds that have many negative effects on our environment. The three major cereals (rice, wheat, maize) account for 2/3 of the global nitrogen fertilizer consumption. A breakthrough in nitrogen use efficiency would decouple rising food production from rising fertilizer consumption, and make farming more profitable.
- Smart fertilizers and genetic improvements that could double the efficiency of phosphorus fertilizer and enable better phosphorus recycling, thus slowing down the consumption of finite mineral phosphate resources.
- Next generation biofuels and other bioenergy solutions that are more energy efficient, mostly use crop residues and biomass waste, and don't consume more agricultural land or natural ecosystems.
- Self-sustained vertical or sky farming in urban areas, as part of local food chains.
- Semi-autonomous farm robots for precision farming at different scales, including for performing tasks that are difficult, laborious or dangerous to humans.
- Edible, commercially viable synthetic meat grown under controlled, energy-efficient conditions to replace livestock products.
- New products made from agricultural by-products and waste, including recycling of chemical elements for other uses.

Many more such ideas have been proposed or are already being pursued. Most of them require large, longer-term public and private sector investment and effective collaboration of scientists worldwide, including scientists from developing countries.

The role of agricultural research and human resources development

Both research and delivery of new technologies and know-how are key ingredients of productivity growth in agriculture. Despite the proven high social returns to public investment in agricultural research and technology in developing countries, and despite a modest reversal in funding in recent years, there is clear underinvestment in this area¹⁰. Investments in agricultural research should receive high priority and they need to be of long-term, strategic nature, not driven by fragmented short-term thinking. It must also be noted that investments in R&D can have significant impact on productivity growth even in the absence of improvements in infrastructure or extension, whereas the reverse is usually not the case³.

Although private sector funding for agricultural R&D has risen substantially in recent years, questions must be raised whether it can really substitute for public R&D²⁶. Generally speaking, private sector R&D is concentrated on fewer commodities, technologies and markets than public R&D and the intellectual property created is not equally accessible. Moreover, a decline in public sector funding would also lead to decline in basic research needed to create new technology opportunities for the private sector, as well as a decline in training of human

resources needed by the private sector. Hence, a balanced approach is needed, including increased investments in public R&D on agriculture and food systems.

Investing in creating and retaining a new generation of agricultural scientists and professionals – including more women – will be vital for achieving any of the post-2015 agricultural development goals. Huge human resources gaps persist in many developing countries, particularly in Sub-Saharan Africa, but, with the exception of perhaps China and India, also in most countries of Asia. Moreover, a generation gap is opening up due to retirements and lacking investments in human resources development during the past 20 years. We can achieve a lot with new technologies, but only if we have dedicated people who develop them, make sure that they meet farmers' needs, and bring them to farmers. Robots, computers or smartphones cannot do that. They are helpful tools, but not the primary means for enacting behavior change in the complex world of agriculture.

Addressing critical data gaps

Implementing an agro-ecological intensification will require more precise decision making for more precise farming, both of which require better data, models, and monitoring mechanisms.

At present, aggregate data and models are widely used to assess the current status and make projections on food demand and supply, agricultural inputs, poverty, hunger and malnutrition. Numerous uncertainties are inherent to this approach, both in terms of the quality of the available data and the assumptions used in projection models. Exaggerations or distortions are not

uncommon. Detailed studies with complex conclusions are often turned into simplistic media messages rather than more nuanced conclusions²⁷. Moreover, many of the actual solutions will need to be implemented at sub-national scales, all the way down to the household, farm, field and even within-field scales where changes in behavior as well as precision farming technologies will be a critical condition for success.

On the demand side, large uncertainties persist in terms of future population growth and structural transformations that are likely to shift food consumption patterns by urban and rural consumers. Africa, India and China are of particular importance for that because they together account for more than half of the world's population. We cannot tell for sure whether the world's population will be 9 or 10 billion people by 2050 or even more. An additional 1 billion people has huge implications for additional food need, but it can easily also result in losing >100 million ha of agricultural land to industrialization and urbanization. Data on consumption are often unreliable, and so are data on postharvest losses and food waste. Existing estimates of key aspects of market behavior (supply and demand elasticities for inputs and outputs) that underpin existing economic models are often sparse and inconsistent. Difficult to assess, understand and project are changes in consumer behavior because of large cultural and economic differences among and within countries. Such information needs to be collected more regularly, at the household level.

Available measures of FAO, the World Bank and other organizations on the number of people classified as living in extreme poverty, chronically hungry or suffering from specific nutritional deficiencies are imperfect. There are poverty headcount maps for many countries. However, we

do not generally have spatial data on poverty gaps or hunger, and hunger data are not really reliable (often balance sheet based). They also need to be disaggregated further more to sub-national and even local scales in rural and urban areas and they need to be updated regularly. Average or aggregate national data that are 10 years old will not help with better targeting of policy decisions and investments to the areas where they are most needed.

Accurate information on cropping area, crop yields, crop/livestock damage by stresses and disasters, climate projections, food consumption, trade, ending stocks, non-food uses of crops, food prices, and postharvest losses is critical for improving market forecasts, early warning systems and policy decisions. It is currently not available for many countries, delayed or only collected at coarse resolution. Instead, it must be spatially dense, transparent and timely, which will also require using new remote sensing technology and forecasting models. Full participation by all information providers and analysts is essential, including those from the private sector. A collaborative effort has recently been initiated to establish a new Agricultural Market Information System (AMIS), but it is currently limited to the G20 countries and few non-G20 countries.

On the supply side, uncertainties also exist about the potential and actual trajectories for agricultural land development and the quality of the associated soils for sustainable crop production, actual crop and animal productivity levels, exploitable productivity gaps, and the use of critical inputs such as fertilizer, irrigation water, and agrochemicals. Some progress has recently been made in disaggregating crop yields and yield gaps at national and sub-national levels ^{4,5}, but these studies have still relied on globally available census data and other relatively

coarse information. The available information on fertilizer and pesticides use by crops is sparse in product detail and spatial resolution, not up to date, and generally not verified at farm-scale. Information on soils and their productivity potential has only marginally improved in recent decades and remains a critical bottleneck in many developing countries. A more precise agriculture will also require long-term and real-time weather information for all major crop-producing regions, with fine spatial resolution.

Agriculture activities have many facets and spinoff impacts. Data and decision tools for assessing the various trade-offs and improving management decisions, productivity and environmental stewardship need to be improved¹. We also need to know more about the adoption of new technologies and about which areas currently used for production of staple food crops are in a spiral of degradation because the natural endowments (soil and climate) are not good enough to support agricultural systems that can lift farmers out of poverty. We need to build a global system for monitoring the performance of crop production at a fine scale²⁸ and reward farmers who make steady progress towards improving their metrics.

We need to be able to predict crop performance on every hectare of existing farmland within 10 years. Complete coverage of all farm land will only be possible through use of new digital technologies, including mobile phone platforms for bottom-up collection of farm and farmer information. A global effort is needed to design, test, and scale the necessary data platforms, analytical and implementation tools, and train human resources in both public and private sector on how to use digital technologies in agriculture.

References

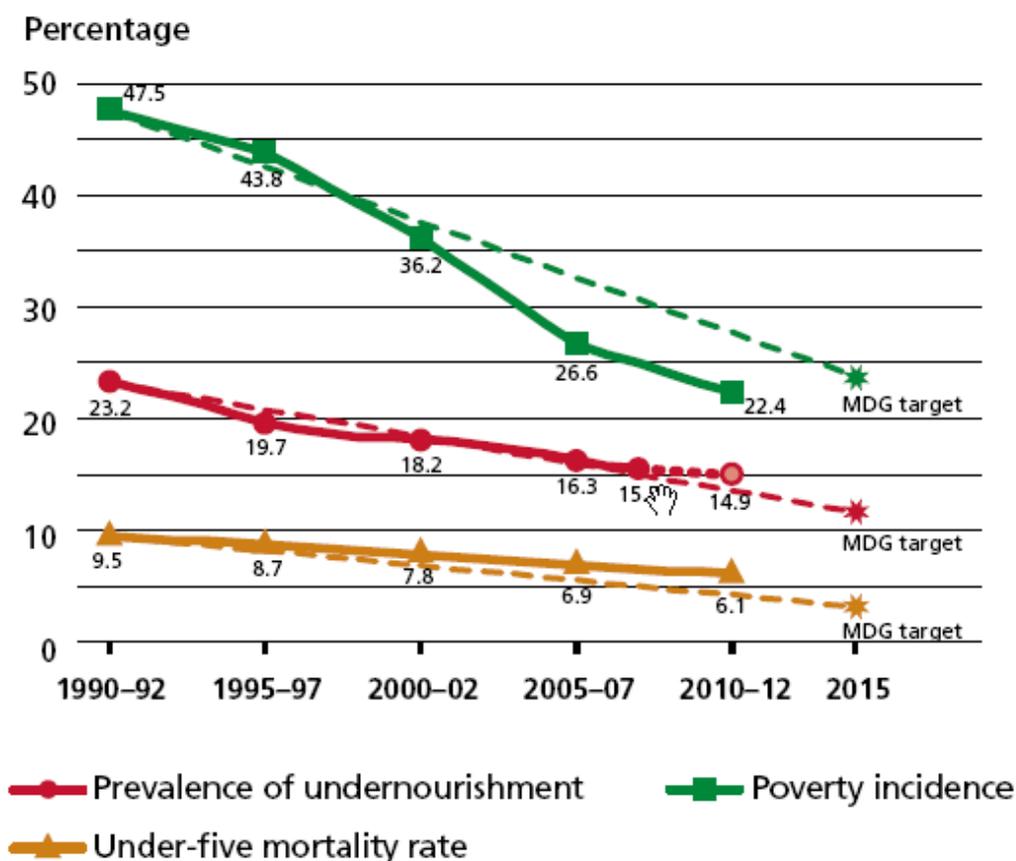
1. Foley, J.A. *et al.* "Solutions for a cultivated planet", *Nature* **478**, 337-342, 2011.
2. Godfray, H.C. *et al.*, " Food Security: The challenge of feeding 9 billion people". *Science* **327**, 812-818, 2010.
3. Fuglie, K.O., Wang, S.L. & Ball, V.E., *Productivity growth in agriculture: an international perspective*, CABI, Wallingford, UK, 2012.
4. Mueller, N.D. *et al.*, "Closing yield gaps through nutrient and water management", *Nature* **490**, 254-257, 2012.
5. Ray, D.K., Ramankutty, N., Mueller, N.D., West, P.C. & Foley, J.A., "Recent patterns of crop yield growth and stagnation", *Nat Commun* **3**, 1293, 2012.
6. FAO-WFP-IFAD, *The state of food insecurity in the world 2012. Economic growth is necessary but not sufficient to accelerate reduction of hunger*, FAO, Rome, 2012.
7. FAO, *Global agriculture towards 2050*, FAO, Rome, 2009.
8. Tilman, D., Balzer, C., Hill, J. & Befort, B.L., "Global food demand and the sustainable intensification of agriculture", *Proc. Natl. Acad. Sci.* **108**, 20260-20264, 2011.
9. FAO, *Looking ahead in world food and agriculture: perspectives to 2050*, FAO, Rome, 2011.
10. FAO, *The state of food and agriculture*, FAO, Rome, 2012.
11. FAO, *State of the world's land and water resources for food and agriculture*, FAO, Rome, 2011.
12. Conway, G., *One billion hungry: can we feed the world?* Comstock Publishing Associates, Ithaca, London, 2012.
13. The Royal Society, *Reaping the benefits: science and sustainable intensification of global agriculture*, The Royal Society, London, 2009.
14. Oxfam, *Growing a better future. Food justice in a resource-constrained world*, Oxfam, Oxford, UK, 2011.
15. WEF, *Realizing a new vision for agriculture. A roadmap for stakeholders*, World Economic Forum (WEF), Geneva, 2010.
16. UNEP, *Avoiding future famines: Strengthening the ecological foundation of food security through sustainable food systems*, United Nations Environment Programme (UNEP), Nairobi, Kenya, 2012.
17. IAASTD, *Agriculture at a crossroads. International Assessment of Agricultural Knowledge, Science and Technology for Development*, Islands Press, Washington, DC, 2009.
18. Vorley, B., Cotula, L. & Chan, M.-K., *Tipping the balance. Policies to shape agricultural investments and markets in favour of small-scale farmers*, IIED & Oxfam, Oxford, 2012.
19. Pretty, J. *et al.*, "The top 100 questions of importance to the future of global agriculture", *Int. J. Agric. Sustainability* **8**, 219-236, 2010.
20. World Bank, *World development report 2008: Agriculture for development*, The World Bank, Washington, DC, 2008.
21. Diao, X.S., Thurlow, J., Benin, S. & Fan, S., *Strategies and priorities for African agriculture. Economywide perspectives from country studies*, International Food Policy Research Institute (IFPRI), Washington, DC, 2012.
22. Cassman, K.G., "Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture", *Proc. Natl. Acad. Sci.* **96**, 5952-5959, 1999.

23. Keating, B.A. *et al*, "Eco-efficient Agriculture: Concepts, challenges, and opportunities", *Crop Sci.* **50**, S-109, 2010.
24. Vitousek, P.M. *et al*, "Nutrient imbalances in agricultural development", *Science* **324**, 1519-1520, 2009.
25. Lowder, S.K., Carisma, B. & Skoet, J., *Who invests in agriculture and how much? An empirical review of the relative size of various investments in agriculture in low- and middle-income countries. ESA Working Paper No. 12-09*, FAO, Rome, 2012.
26. Fuglie, K., Heisey, P., King, J., Pray, C.E. & Schimmelpfennig, D., "The contribution of private industry to agricultural innovation", *Science* **338**, 1031-1032, 2012.
27. Swinnen, J. & Squicciarini, P., "Mixed messages on prices and food security", *Science* **335**, 405-406, 2012.
28. Sachs, J. *et al*, "Monitoring the world's agriculture", *Nature* **466**, 558-560, 2010.

Annex: Supplementary figures and tables

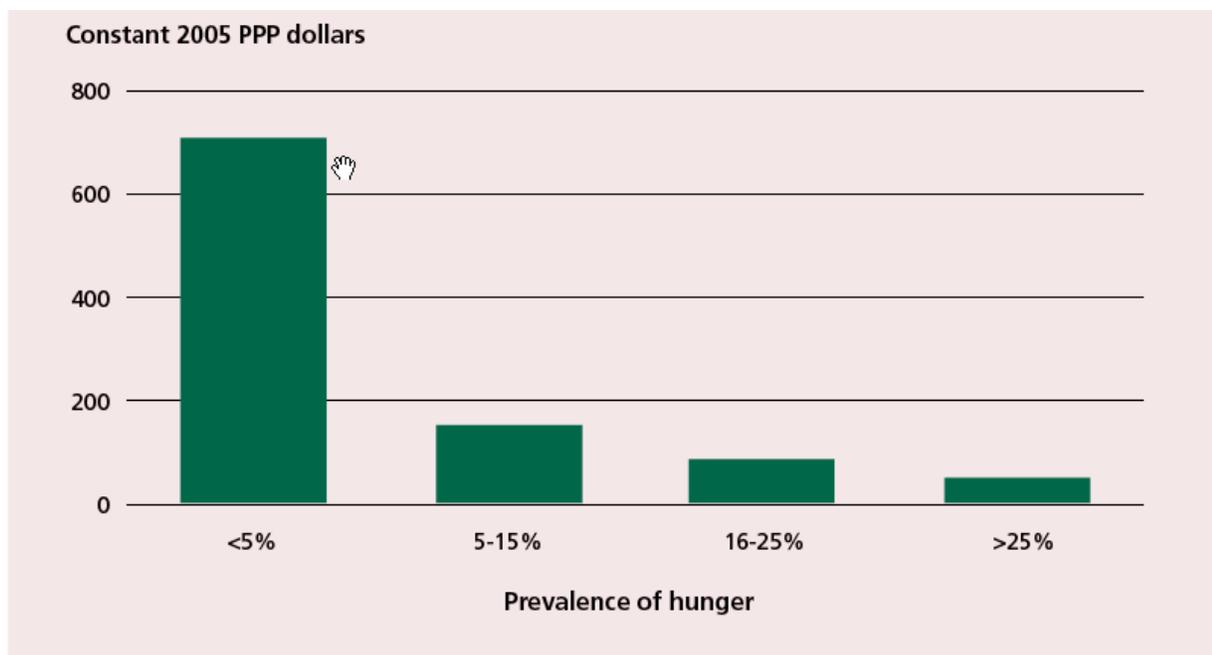
Global progress towards selected MDGs in the developing world that are much affected by agriculture. It should be noted that although the prevalence of undernourishment in developing countries has declined from about 23% in 1990-92 to 15% in 2010-12, the total number of undernourished people has remained unchanged from 2007-2012 and amounts to about 852 million people (including 304 million in South Asia, 234 million in Sub-Saharan Africa, 167 million in Eastern Asia and 65 million in Southeast Asia).

Source: FAO-WFP-IFAD, *The state of food insecurity in the world 2012. Economic growth is necessary but not sufficient to accelerate reduction of hunger* (FAO, Rome, 2012).



Government expenditures on agriculture per worker, by prevalence of undernourishment.

Source: Fig. 3 (p. 6) in *The state of food and agriculture* (FAO, Rome, 2012).

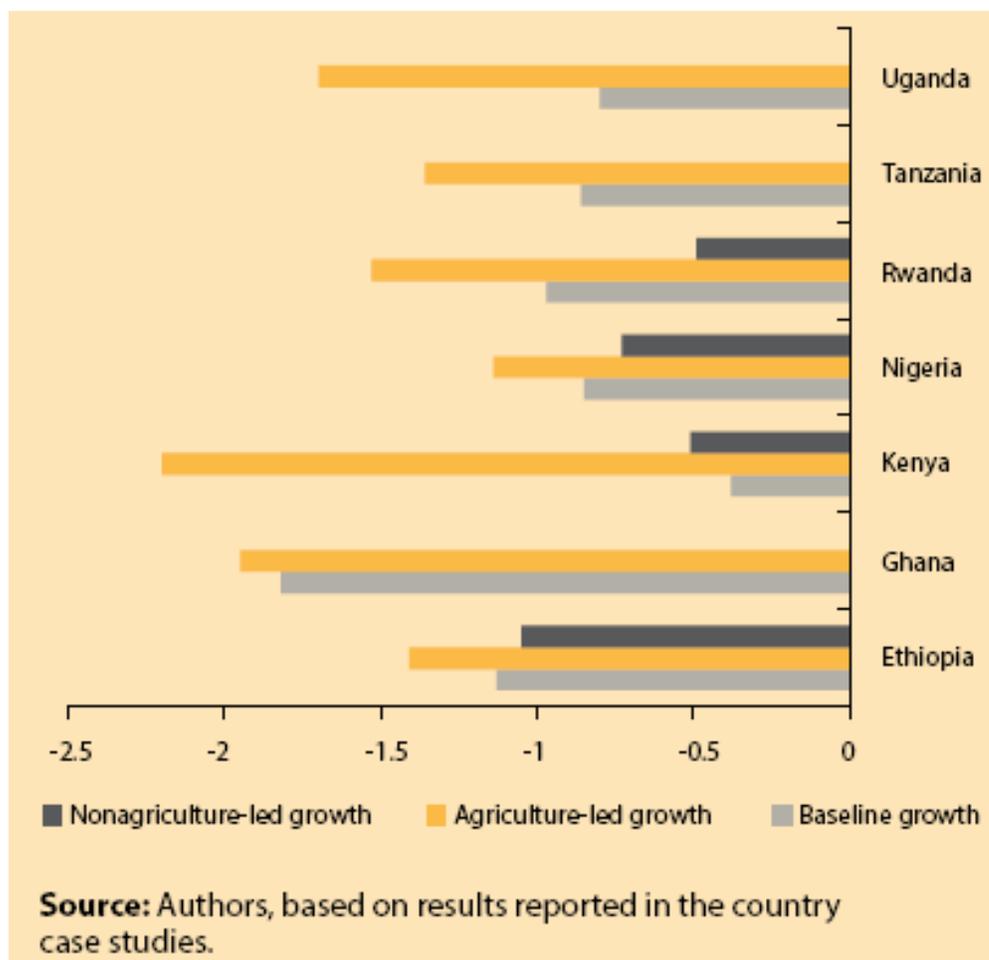


Notes: Government expenditure per worker is the annual average for 2005–07 and the prevalence of undernourishment is the FAO estimate for the years 2010–12.

Source: Authors' calculations using IFPRI, 2010 and FAO, IFAD and WFP, 2012.

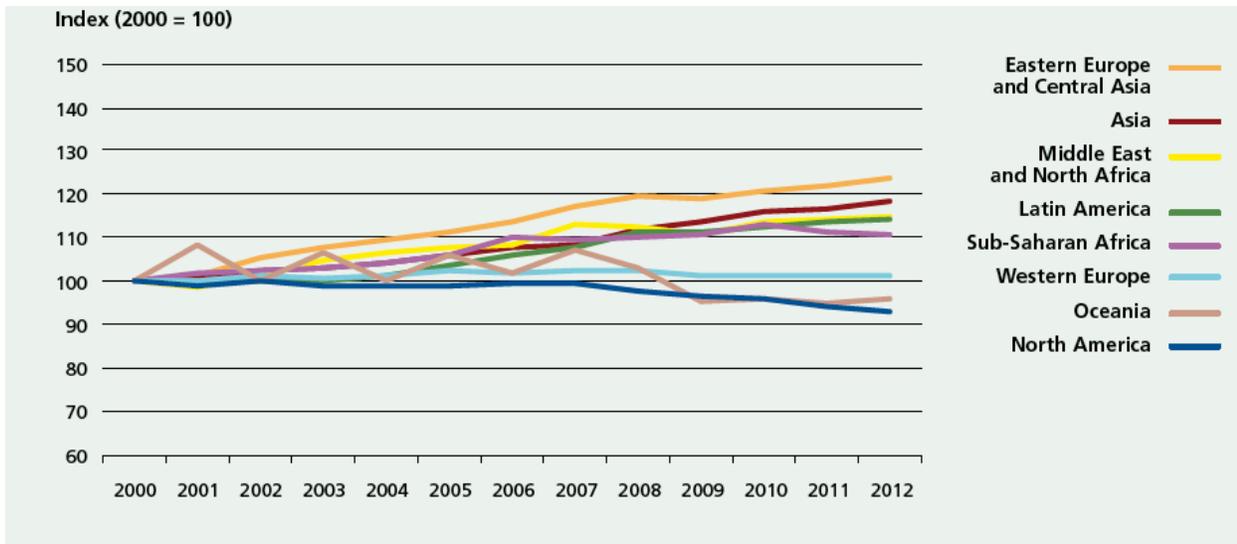
Percent change in national poverty rate resulting from a 1% change in total GDP growth.

Source: *Strategies and priorities for African agriculture. Economywide perspectives from country studies* (International Food Policy Research Institute (IFPRI), Washington, DC, 2012).



Per capita food consumption by region.

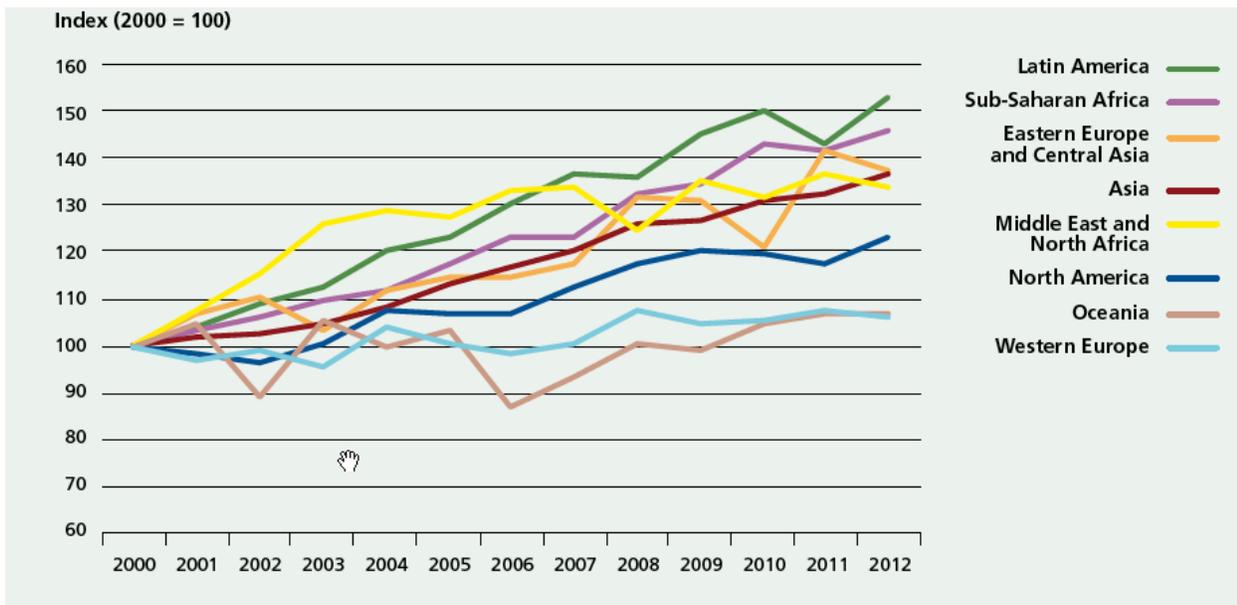
Source: Fig. 32 (p. 103) in *The state of food and agriculture* (FAO, Rome, 2012)



Notes: Food consumption of crops and livestock evaluated at 2004–06 constant international reference prices. Data for 2012 are projections; those for 2011 are provisional estimates.
Source: FAO.

Net production by region.

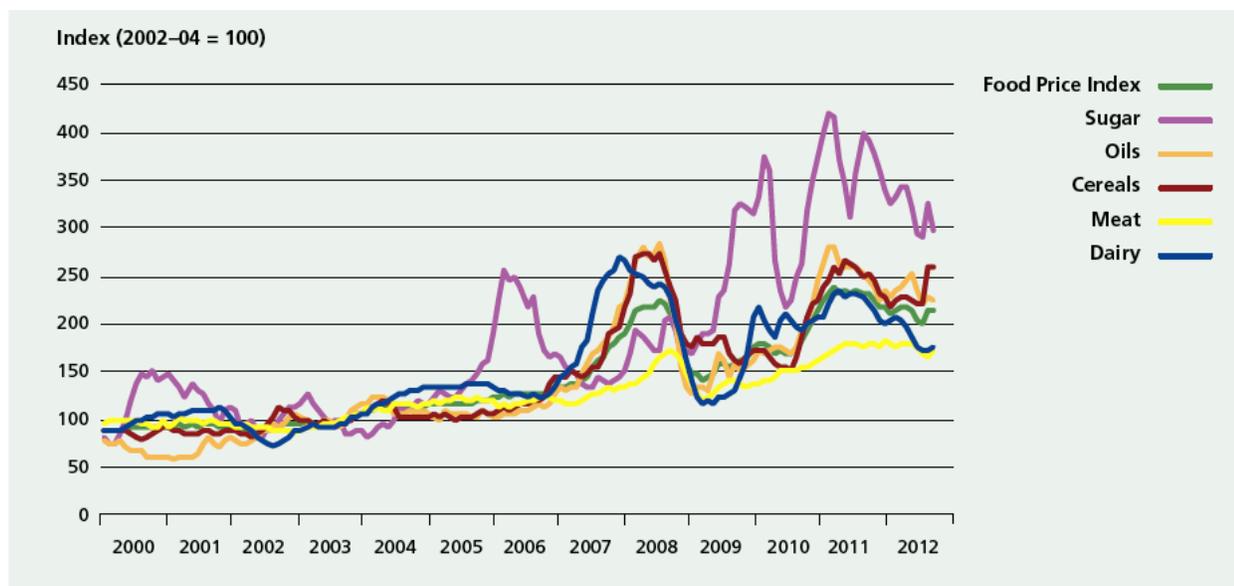
Source: Fig. 31 (p. 102) in *The state of food and agriculture* (FAO, Rome, 2012)



Notes: Net production is gross production of crops and livestock net of feed and seed evaluated at 2004–06 constant international reference prices. Data for 2012 are projections; those for 2011 are provisional estimates.
Source: FAO.

FAO Food Price Index and indices of constituent commodities, 2000 to August 2012.

Source: Fi. 28 (p. 99) in *The state of food and agriculture* (FAO, Rome, 2012)



Note: The price indices are monthly observations plotted from January 2000 through August 2012. They reflect actual prices, not adjusted for inflation.
Source: FAO.

<http://www.fao.org/worldfoodsituation/wfs-home/foodpricesindex/en/>

Total factor productivity growth in agriculture in selected regions and countries.

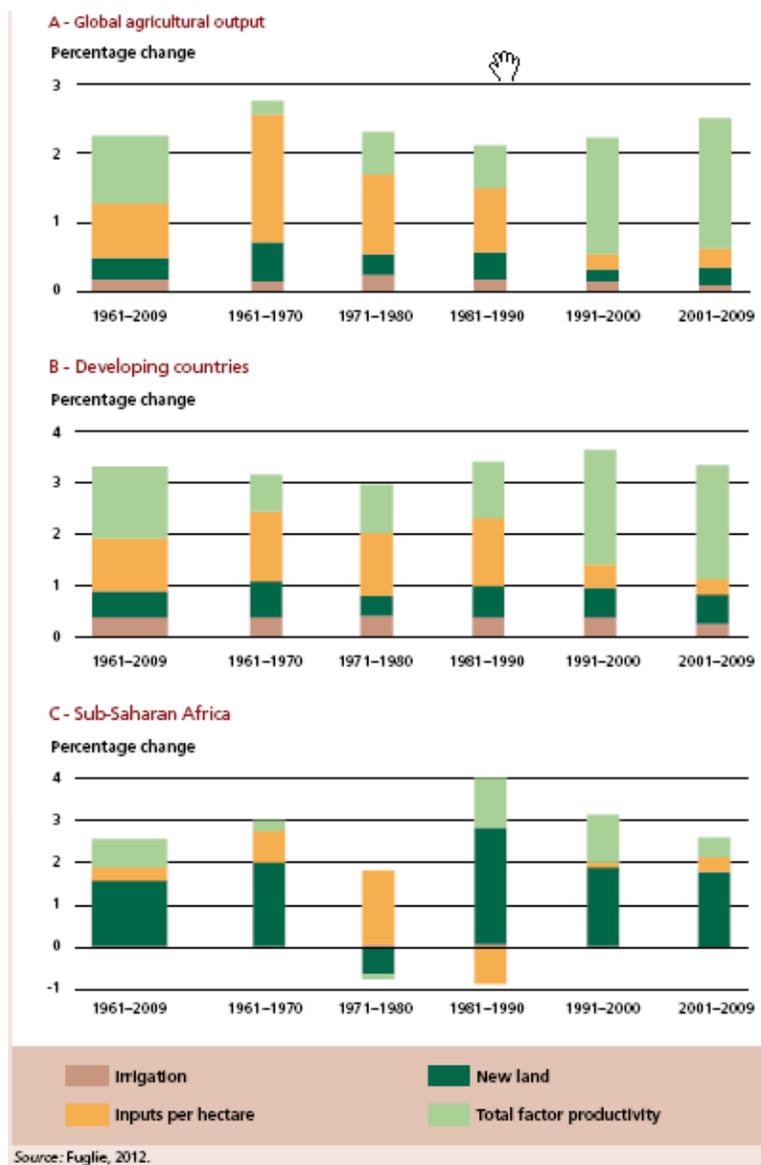
Source: Table 15 (p. 105) in *The state of food and agriculture* (FAO, Rome, 2012)

	AVERAGE ANNUAL GROWTH RATE				
	1961-1970	1971-1980	1981-1990	1991-2000	2001-2009
All developed countries	0.99	1.64	1.36	2.23	2.44
All developing countries	0.69	0.93	1.12	2.22	2.21
North Africa	1.32	0.48	3.09	2.03	3.04
Sub-Saharan Africa	0.17	-0.05	0.76	0.99	0.51
Latin America and the Caribbean	0.84	1.21	0.99	2.30	2.74
Brazil	0.19	0.53	3.02	2.61	4.04
Asia	0.91	1.17	1.42	2.73	2.78
China	0.93	0.60	1.69	4.16	2.83
Transition countries	0.57	-0.11	0.58	0.78	2.28
Russian Federation	0.88	-1.35	0.85	1.42	4.29

Source: Fuglie, 2012.

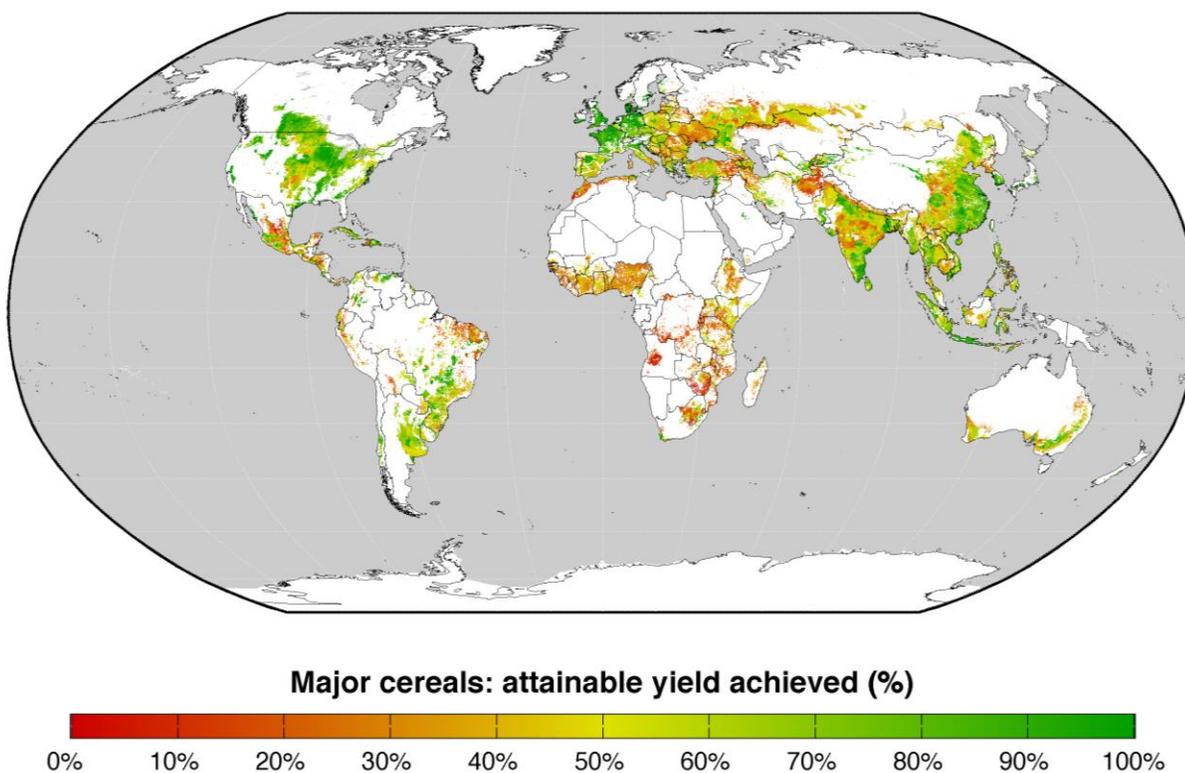
Growth in agricultural output, by source of growth and time period.

Source: Box 7 (p. 33) in *The state of food and agriculture* (FAO, Rome, 2012)



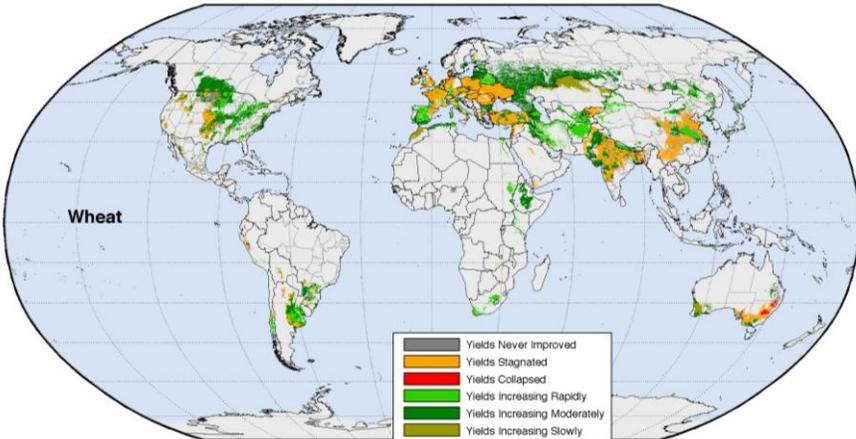
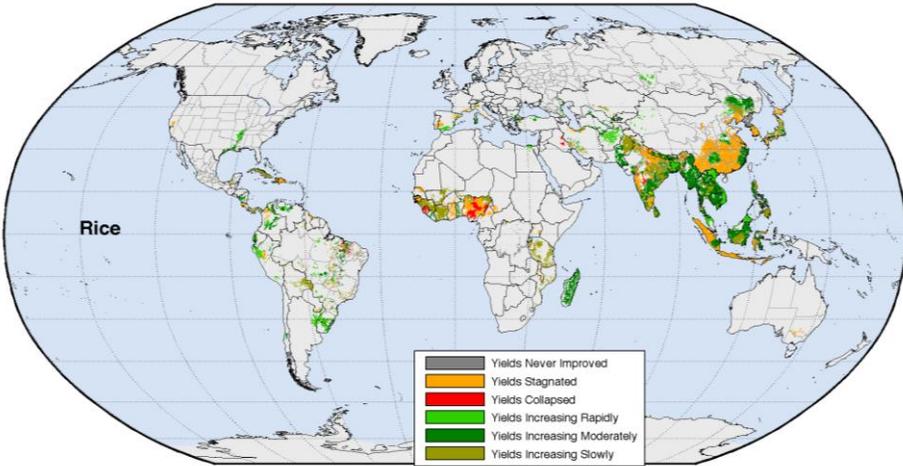
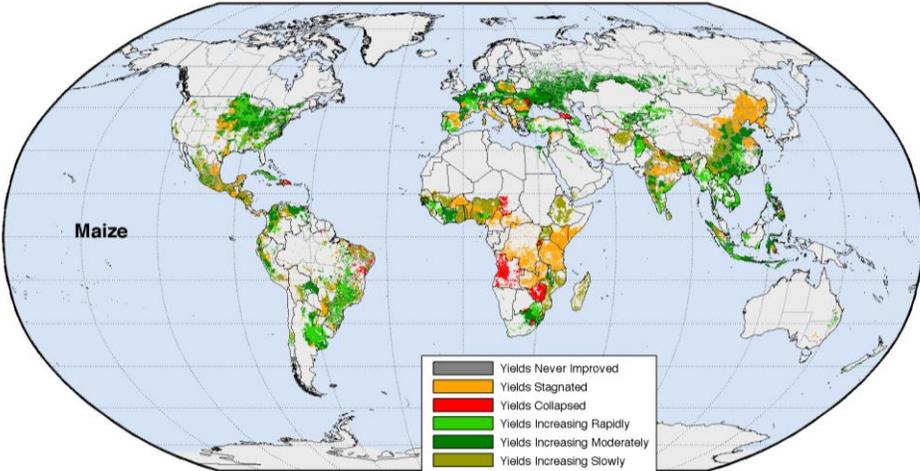
Estimated actual yields of major cereals (maize, rice, wheat) as percent of climate-specific yields that could be attained with currently available technologies (as of circa 2000). It should be noted that data quality may be poor in some countries.

Source: Mueller, N. *et al.* Closing yield gaps through nutrient and water management. *Nature* **490**, 254 (2012).



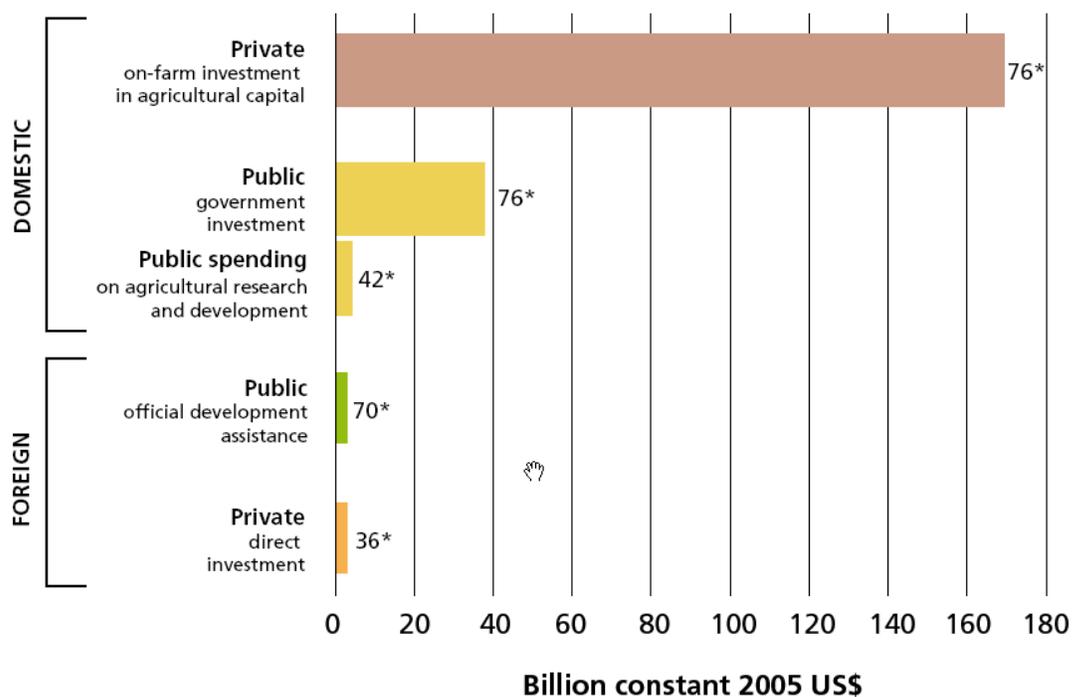
Global maps of grain yield trends of major cereals (maize, rice, wheat) during 1961-2008. It should be noted that data quality may be poor in some countries.

Source: Ray, D.K. *et al.* Recent patterns of crop yield growth and stagnation. *Nat Commun* 3, 1293 (2012).



Investments in agriculture by source in selected low- and middle-income countries. Data are averages for 2005-2007 or for the most recent year available. Domestic private investment refers to farmers and local businesses. * indicates the number of countries.

Source: Fig. 5 (p. 14) in *The state of food and agriculture* (FAO, Rome, 2012) and Table 2 (p. 15) in S. K. Lowder, B. Carisma, J. Scoet, *Who invests in agriculture and how much? An empirical review of the relative size of various investments in agriculture in low- and middle-income countries. ESA Working Paper No. 12-09* (FAO, Rome, 2012)



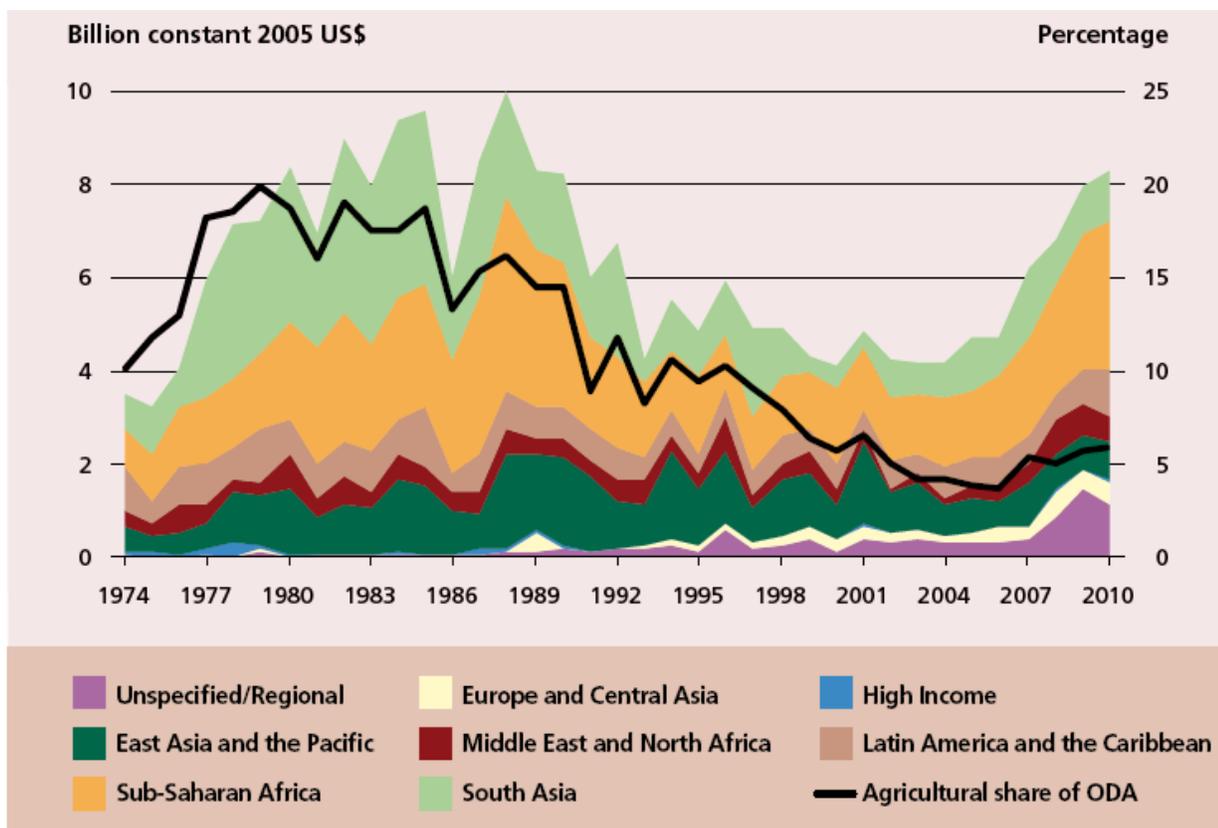
	On-farm investment in agricultural capital (76)	Government investment (76)	Public spending on agricultural R&D (42)	Official development assistance (70)	Foreign direct investment (36)
	Millions of US dollars				
East Asia and the Pacific	51,675	20,607	1,693	682	1,675
East Asia and the Pacific, excluding China	17,297	3,194	369	522	998
Europe and Central Asia	21,791	4,138		78	383
Latin America and the Caribbean	26,483	2,910	1,356	213	1,225
Middle East and North Africa	12,864	3,594	427	194	67
South Asia	36,726	4,715	703	912	10
Sub-Saharan Africa	19,038	1,993	539	1,027	20
Low- and middle-income countries	168,577	37,957	4,718	3,106	3,380

Notes: See Figure 2.

Sources: On-farm investment in agricultural capital is calculated using data on agricultural capital stock from FAO (2012). Government investment is estimated using data from IFPRI (2012a), public spending on agricultural R&D is from IFPRI (2012b), official development assistance is estimated using data from OECD (2012) and foreign direct investment data are from UNCTAD (2011).

Level and share of official development assistance committed to agriculture, by region.

Source: Fig. 14 (p. 34) in *The state of food and agriculture* (FAO, Rome, 2012).



Source: Authors' calculations using data from OECD, 2012a. See Annex table A7.

Returns to public spending in terms of agricultural performance (increased productivity per same monetary unit) and poverty reduction (no. of poor people per monetary unit) in Uganda.

Source: Figures 24-25 (p. 78-79) in *The state of food and agriculture* (FAO, Rome, 2012).

