SUSTAINABLE DEVELOPMENT
SOLUTIONS NETWORK
A GLOBAL INITIATIVE FOR THE UNITED NATIONS

Solutions for Sustainable Agriculture and Food Systems

TECHNICAL REPORT FOR THE POST-2015 DEVELOPMENT AGENDA

18 September 2013

Prepared by **the Thematic Group on Sustainable Agriculture and Food Systems of the Sustainable Development Solutions Network**

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The Sustainable Development Solutions Network (SDSN) engages scientists, engineers, business and civil society leaders, and development practitioners for evidence-based problem solving. It promotes solutions initiatives that demonstrate the potential of technical and business innovation to support sustainable development (www.unsdsn.org).

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Executive Support

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Members of the Thematic Group serve in their personal capacities; the opinions expressed in this paper may not reflect the opinions of their institutions. A draft version of this report was made available for public consultation from 25 July to 15 August 2013. The Thematic Group is grateful for the hundreds of detailed submissions received in writing from experts representing the institutions listed below. Any remaining errors or omissions are the sole responsibility of the authors.

ADM Institute; Asian-Pacific Resource and Research Centre for Women (ARROW); Borlaug Institute; Brighter Green; CABI; Columbia University; Concern Worldwide; CropLife; EcoAgriculture Parters; FAO; GIST Advisory; GFAR; Greenpeace; ICBA; IFA; ILRI; International Christian University; IPNI; IRRI; John Deere; KEHYS; Michigan State University; Monsanto; Nestle; University of London; University of Nebraska; University of Perugia; Usmanu Danfodiyo University; USDA; Vale Columbia Center; Wageningen University and Research Centre; World Bank; WSPCA

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Preamble

It is hard to exaggerate the role that agriculture plays in human development. This report shows the multi-faceted contributions of the global food system to all pillars of sustainable development in the post-2015 era. It recognizes the need to eradicate poverty and hunger in our generation, and it also points out the importance of having an integrated agricultural and rural development goal in the sustainable development agenda.

The report aims to outline principles for developing more specific solutions that are adaptable to local realities. Perhaps the only commonality of agricultural systems worldwide is that they provide that most critical resource, food. Beyond this, agricultural systems are incredibly diverse, with crops, livestock, climates, soils, tools, and technology varying from country to country and even farm to farm. Therefore, we have tried our best to avoid generic prescriptions of any kind. One-size-fits-all solutions are unlikely to work and solutions will need to be tailored to address regional and site-specific barriers to sustainability. This adaptation process will require the engagement of diverse stakeholders and sectors.

Our objective is to advance the process of setting global, science-based goals and targets. The SDGs, targets, indicators, and solutions we propose are meant to be examples to spur further discussion. They will require validation and tailoring of concrete strategies in each country. We encourage all stakeholders to participate actively in further efforts to define the post-2015 agenda, and in taking action to advance sustainability.

This report has benefitted from substantial input from many people, including the members of the Thematic Group and hundreds of suggestions received from experts representing all sectors of agriculture and food systems. The authors have inevitably brought their biases to the document, and perhaps focused primarily on science and technology solutions. We recognize that many other areas may not have received due attention, including strategies for reforming agriculture and food systems in industrialized countries, biofuels, agricultural policies and trade, food aid, land tenure, financing, farm insurance, alternative agriculture, counterfeit farm inputs, fisheries, agroforestry, environmental and health issues of agrochemicals, and ecosystem services management, to name a few.

To many, entering a sustainable development path for agriculture and food seems like a daunting challenge. We believe that it is feasible. The overarching motive for this report is to encourage people to act, despite the enormous challenges, or as John F. Kennedy said:

"By defining our goal more clearly, by making it seem more manageable and less remote, we can help all people to see it, to draw hope from it, and to move irresistibly towards it."

What are some of the tough questions that need to be addressed?

- How can we make farming more profitable and more sustainable in our generation?
- How can consumer behavior be changed towards healthier diets and wasting less food? Will aspiring consumers in Asia follow the same food consumption model as in the West?
- Will China import more food and thus also water, nutrients and energy from other countries? How can it transform its own agriculture to produce enough food in a sustainable and safe manner?
- How can India direct more of its economic growth towards rural development and eradicating widespread poverty and malnutrition?
- How can Africa utilize its land and water resources better? What will be the role of large-scale commercial agriculture development compared to smallholder production?
- What will be the future role of Latin American countries that still have arable land and water resources that could be tapped? What should be produced there? How?
- How can the double poverty trap of small farms with poor soils be overcome? Will rural development and job creation require more consolidation of farms into greater sizes or business entities that could be more productive and sustainable?
- How can agriculture become an attractive entrepreneurial undertaking, reducing drudgery, reducing unemployment, and getting people - women and youth in particular - decent and fulfilling work?
- How can biotechnology best contribute to future food and nutritional security and serve the needs of the poor?
- To what extent can agroecological principles be harnessed in soil, plant and pest management, to substitute for and/or improve the efficiency of external inputs?
- How much can organic agriculture contribute to feeding the world? Where and at what cost?
- How much can urban farming contribute to feeding the world? Where and at what cost?
- How can we capitalize on the revolutions in genomics, IT, physics, biology, chemistry, and material sciences to take agriculture to a new level? Who will invest in strategic blue-sky research?
- How can countries make the best choices for a sustainable agriculture development path and what should be the role foreign aid in it? How can we ensure that investments are motivated by facts and priority needs rather than political interests?
- How should current global, regional, and national policies on subsidies and trade be changed to enable equitable and sustainable agricultural development?
- How can we improve the business climate to encourage more investment and small business development? What new mechanisms and incentives can be provided for public, civil society and private sector actors to work more effectively together?
- What could be new, more effective models for agricultural extension?
- What should be the future investment models for agricultural research and development?
- Do current agreements and laws on plant genetic resources and other intellectual property serve future needs? How can we ensure that intellectual property is honored but also accessible to poorer countries as well as small- and medium-sized businesses?
- What are the concrete targets and metrics for measuring the performance of the agriculture and food sector? How can they be monitored at a disaggregated level?

Summary

Agriculture faces many challenges, making it more and more difficult to achieve its primary objective - feeding the world – each year. Population growth and changes in diet associated with rising incomes drive greater demand for food and other agricultural products, while global food systems are increasingly threatened by land degradation, climate change, and other stressors. Uncertainties exist about regional and local impacts of climate change, but the overall global pattern suggests that the stability of the food system will be at greater risk due to short-term variability in food supply.

Agriculture must change to meet the rising demand, to contribute more effectively to the reduction of poverty and malnutrition, and to become ecologically more sustainable. This transformation will be crucial for achieving many of the post-2015 Sustainable Development Goals (SDGs). Poverty and hunger must be eradicated in our generation and should therefore be a prominent stand-alone goal. The majority of the world's poor people live in rural areas, and agriculture growth has proven effective in lifting rural families out of poverty and hunger. Managing the linkages between agriculture, poverty and nutrition is critical as we look towards providing children with an opportunity to reach their full potential. The new agenda should also have a goal that explicitly focuses on improving agricultural systems and addresses rural development in an integrated manner, as underscored also by the interim report of the Open Working Group. Food and nutrition security targets are fully embedded in these two goals. The contributions of agriculture to goals on gender equality and social inclusion, health, climate change and energy, ecosystem services and natural resources, and good governance must also be recognized in specific targets and indicators for these goals.

Sustainable Agricultural Intensification (SAI)[a] offers workable options to eradicate poverty and hunger while improving the environmental performance of agriculture, but requires transformative, simultaneous interventions along the whole food chain, from production to consumption. It also requires unprecedented, large-scale behavior change by consumers as well as producers of food. Major elements of a sustainable development path for agriculture and food systems are:

- Shifting towards healthier diets;
- Ensuring the supply of safe, nutritious food to all through increasing agricultural productivity on existing crop and pasture land and making it more resilient to climatic extremes;
- Preserving the environment through systems management principles that increase resource efficiency, reduce net carbon emissions and other pollutants associated with agriculture, and improve soils and conserve natural resources;
- Reducing food losses and waste;
- New visions and business models for smallholder agriculture and rural development that create economic and job opportunities and make rural areas more attractive places to live;
- Empowering women along the value chain;
- Coherent policies at all levels that stimulate behavior change, align all actors, provide secure rights to land and other resources, and incentivize solutions for sustainable intensification of agriculture and food systems that take advantage of rapid advances in science and technology.
- Clear goals, targets and indicators that address critical areas of food production and consumption, motivate people and provide a structured approach to guide countries in designing their own development paths for agriculture;

[a] Sustainable Agricultural Intensification (SAI) includes the application of genetic, agro-ecological, and socioeconomic

- Monitoring agriculture and food systems at unprecedented level of detail;
- Long-term vision and investments in capacity building and research.

A key principle to recognize is that - given the huge diversity of agriculture and of the starting points for change - there can be no one-size-fits-all solutions. Countries should follow the most suitable pathways and timelines for addressing their specific challenges through tailored SAI solutions, policies, monitoring and other implementation mechanisms. Solutions are workable options that can be tailored to raising system productivity or diversity, efficiency, resilience, value and profitability of farming, including the enabling mechanisms needed within diverse local contexts. Advances towards SAI will be most effective and durable where all stakeholders work together to bring their ideas and support to developing and implementing site-specific solutions that allow for iterative, continuous improvement of the world's food systems and their key components.

Long-lasting solutions will require re-thinking of rural development and smallholder agriculture towards structural transformations that include and benefit the poor. Improved farming systems and new technologies and business models can create decent jobs, allow the overcoming of resource constraints, enable greater market participation, and also lessen physical hardships in agriculture, particularly for women and youth. Agriculture in industrialized countries will also need to change, including changes in policies that affect many low- and medium-income countries. High-income countries will have to embark on a pathway that addresses urgent issues such as unhealthy diets, food waste, the right balance of food vs. biofuels production, and fair agricultural policies. These countries will also have to lead in demonstrating how higher standards of productivity, resource efficiency, food safety and traceability, and environmental impact can be met. This can also provide important lessons for developing countries in terms of technologies and policies to consider.

New technologies will make it possible for sustainable agriculture to become the new global standard, not the exception; the main factors resisting change are political will, lack of policy coherence at many levels, financing, governance and human behavior. Many of the solutions needed are known or could, with wise investments, become available in the next 10-20 years. Early action is important, but more support and better mechanisms are needed for long-term thinking and action, including strengthening public research and development (R&D), human resources development, and institutional change. We propose evidence-based indicators that could be applied to track progress towards meeting the new Sustainable Development Goals (SDGs) and their Targets, at local, national, regional and global scales. Their effective use will require investing more in monitoring agriculture and food systems, taking advantage of rapid advances in digital information technologies.

The transformation of agriculture will also require re-thinking of international and national structures. The global food system should morph into a true global partnership that widely shares information, experiences and new technology, following open access principles and practices that honor intellectual property but enable wide access and use. Otherwise progress in implementing SAI will be slow, and consequently goals and targets for sustainable development will not be met in many countries. New models for implementation are needed that unlock the real potential of farmers, public and private sectors in solving complex problems. The private sector will be a key player in sustainable agriculture and food systems. Good governance will be essential, including supporting farmer groups, managing risks, and deploying tools and accountability measures that foster greater private sector investment in agriculture, but also put clear constraints on unsustainable or inequitable exploitation of land, water, forests and fisheries.

1. Agriculture is at the center of sustainable development

1.1. Challenge domains for agriculture and food

Agriculture[b] - the supplier of that basic human need, nutrition - is the world's largest user of land, occupying more than one third of Earth's terrestrial surface and also using vast amounts of water. It affects our daily life in many ways, both directly and indirectly. Humans expect agriculture to supply sufficient nutrients, economically and culturally valued foods, fibers and other products. Agriculture must also provide desirable employment and optimized land use and productivity in relation to limiting resources. It must coexist with the needs of urban and natural environments, landscapes and a wide range of other ecosystem services. Agriculture is essential for inclusive development because it produces food as well as economic wealth for many of the world's poorest people – wealth that allows for improved livelihoods through better health care, education, infrastructure improvements and greater investment in environmentally sound practices. For Sub-Saharan Africa, growth generated by agriculture is eleven times more effective in reducing poverty than GDP growth in any other sectors[1].

The development of agriculture was essential for the rise and survival of early civilizations[2]. Increases in the world's population from 800 million at the start of the industrial revolution in 1790 to just over 7 billion today and the prospect that the human population will grow to around 9.3 billion in 2050 have created new concerns about our ability to feed the world in a sustainable manner. The agricultural community has had tremendous success in increasing 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 such as rice, wheat and maize has roughly tripled since 1960, resulting in corresponding decreases in food prices[3]. New estimates show that investments in crop improvement that led to unprecedented yield increases during the Green Revolution saved an estimated 18-27 million hectares of natural ecosystems from being converted to agriculture[4]. The transformation of agriculture benefited from technological innovations and inexpensive fossil fuels to raise agricultural productivity in many world regions, but also left others behind, particularly Sub-Saharan Africa[5].

Progress has been made in reducing global hunger (protein-energy malnutrition) from about 1 billion people in 1990-1992 (18.6% of total population) to about 870 million[c] in 2010-2012 (12.5%)[6]. Yet, global progress in reducing hunger has varied greatly by region and has slowed since 2007. Further, the effects of recent food price spikes relative to household incomes and economic opportunities have not yet been fully accounted for, food prices are expected to remain high, and hidden hunger (micronutrient deficiencies) and other forms of malnutrition remain widespread or have emerged. Many countries, particularly in Sub-Saharan Africa, still face major food and distribution gaps[7]. Unacceptably, every day more than 8,000 children die from undernutrition, despite unprecedented global growth in wealth and technology.

About 70% of the world's very poor people live in rural areas, and a large proportion of the poor and hungry are children and young people[8]. This figure is higher in South and Southeast Asia and Sub-Saharan Africa, where three quarters of the poor live in rural areas. The prevalence of rural poverty is a

[b] **Agriculture** refers broadly to the cultivation of animals, plants and other life forms for the production of food, fiber, biofuels, raw materials, drugs and others purposes, including aquaculture and agroforestry.

[c] FAO projections. This includes 304 million people in South Asia, 234 million in Sub-Saharan Africa, 167 million in Eastern Asia, 65 million in Southeast Asia, and 42 million in Latin America. In Asia and the Pacific the number of undernourished people decreased from 723 million to 528 million during the past two decades, whereas in Africa and the Near East it increased from 192 million to 275 million[6]. Data quality is uncertain for many countries.

challenge that can be met by improving agricultural performance, improving market access and reducing the risks faced by farmers, and investing in rural infrastructure and enterprise.

Meeting world food demand conflicts with current trends of increasing competition for land, water and other natural resources by non-agricultural sectors[9], and needs to be accomplished under a more extreme and also more uncertain future climate in many parts of the world. For many countries, coping with water scarcity and building resilience[d] for adaptation to climate change in the agriculture sector have become top priorities[10]. Reducing agriculture's environmental footprint while ensuring global food and nutritional security[11] will be especially difficult as 87% of the population in 2050 will live in the presently developing world, including 27% in least developed countries. This is the portion of the world's population for which economic growth will be highest and for which increasing incomes will also shift dietary patterns towards increasing demand for food. This is also where there will be increased pressure on many ecosystem services, especially in the tropics. In the past two centuries, 27% of the world's tropical forests, 45% of temperate forests, 50% of the savannahs and 70% of natural grasslands have been converted to agriculture[12], with agriculture being the major driver for deforestation worldwide, leading to the large share of GHG emissions attributed to the sector[13].

Crop intensification has enabled increases in food production and labor productivity without putting more land under cultivation, but this often comes at a price, such as land degradation through soil erosion, inappropriate irrigation and land management practices, loss of soil organic matter and nutrients, depletion of freshwater resources, pollution of waterways and marine environments through inappropriate use of nutrients and crop protection products, increased greenhouse gas (GHG) emissions, and reduction in biodiversity and ecological resilience through dependence on a reduced number of species and varieties. If the environmental costs involved were properly accounted for, the real costs of producing food would be much higher. Is it feasible to continue with a consumption model that largely treats natural resources such as soil, water, and air as "free" goods?

Crop and animal production systems are hugely diverse. A good framework is needed to identify entry points that can lead to the desired outcomes of reducing poverty, improving food security from household to global scale, enhancing population nutritional and health status, and reducing agriculture's environmental footprint. Such a framework must consider the trade-offs and outcomes explicitly, across different scales. To identify entry points for action, three challenge domains are identified as: (1) Sustainable intensification of agricultural systems for food security with high resource use efficiency and environmental protection, (2) Poverty alleviation, economic and social rural development, and (3) Food systems for nutritional security and better health.

Sustainable intensification of agricultural systems for food security and environmental protection

High food prices slow down economic growth[14]. After decades of decline, food prices began to rise slowly in the early 2000s and more sharply after 2005 (Fig. 1-1). Since a spike in 2008, commodity prices have fluctuated, reflecting a different market context for agricultural products than prevailed for the previous half century. It should also be noted that the commonly used food price indices have shortcomings because they measure prices against the earning power of populations which have experienced substantial economic and income growth, and thus do not represent the conditions of the poorest and most food insecure members of global society[15].

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[d]**Resilience** is the ability of agricultural systems and communities to recover successfully from adverse shocks through the capacity for adaptation and transformation. It involves being able to adapt to a changing and increasingly unpredictable environment, and the ability to learn from disturbance. In agriculture, a production system should be resilient and contribute to increased production of food or other products over time.

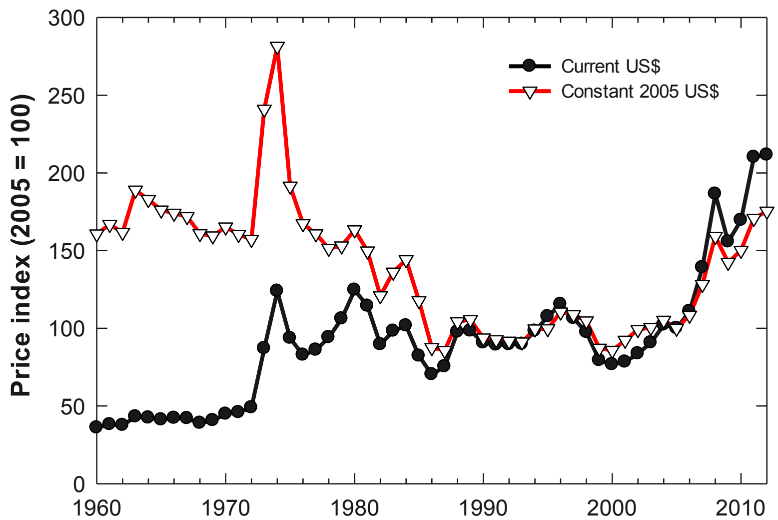

Figure 1-1. Global food price index, current and constant US dollars, 1960-2012.
Source: World Bank Commodity Price Data (Pink Sheet).

Supply and demand balances for agricultural products have become tighter. Global food demand will continue to increase for at least another 50 years due to increasing population and changes of diet. A rapidly expanding middle class in transition countries is expected to further increase the demand for fruits, vegetables, livestock products (milk, meat and eggs) and fish, but generally also for more processed, packaged and branded food. While economic growth will generally lead to an improvement in nutrition in low- and middle-income countries, both rural and urban food and nutrition insecurity remain challenges because of rising numbers of people with low and unstable incomes living in settlements with inadequate infrastructure, including inadequate access to food[16]. In many developing countries, urban and rural households that are net buyers of food often spend half of their income on food, have limited means to store it, are exposed to natural disasters and disease epidemics, and are also the most vulnerable to shocks.

It is difficult to make accurate predictions of future demand for food and other agricultural products because consumption depends on demographic trends, economic growth, behavioral choices and policy decisions, i.e., to what extent countries and their citizens commit to a sustainable development path. If recent trends in population and per-capita wealth continue, feeding a world population of about 9 billion people in 2050 would require raising aggregate global food production by at least 60-70%. Many developing countries may have to even double their food production to nourish their rapidly growing populations[17,18]. It is likely that the demand growth for cereals will be less than demand growth for food in the aggregate, but one can also imagine a scenario in which both cereal and livestock production may have to double within that period if meat consumption and bioenergy use of crops accelerate[19]. Under such a scenario, it will be difficult to meet simultaneously the goals on eradicating poverty and hunger while also safeguarding the environment (Annex 1).

On the positive side, annual growth in global agricultural output has remained fairly steady at 2.1 to 2.5% over the past five decades (Fig. 1-2). The contribution of technological change to agricultural productivity, measured as total factor productivity (TFP)[e], has shown a remarkable increase, from less than 0.5% annual growth in the 1960s to greater than 1.8% annual growth in the 2001-2009 decade. In other words, TFP growth accounted for three-fourths of the total growth in global agricultural production during the past decade, outpacing area expansion and input intensification as the primary source of growth in world agriculture[5]. However, TFP growth has been uneven worldwide. Countries with strong investments in agriculture, including strong research and development (R&D) capacity (e.g., China and Brazil), have demonstrated high productivity growth. By contrast, growth has slowed elsewhere and remains slow in many food-insecure countries in Sub-Saharan Africa.

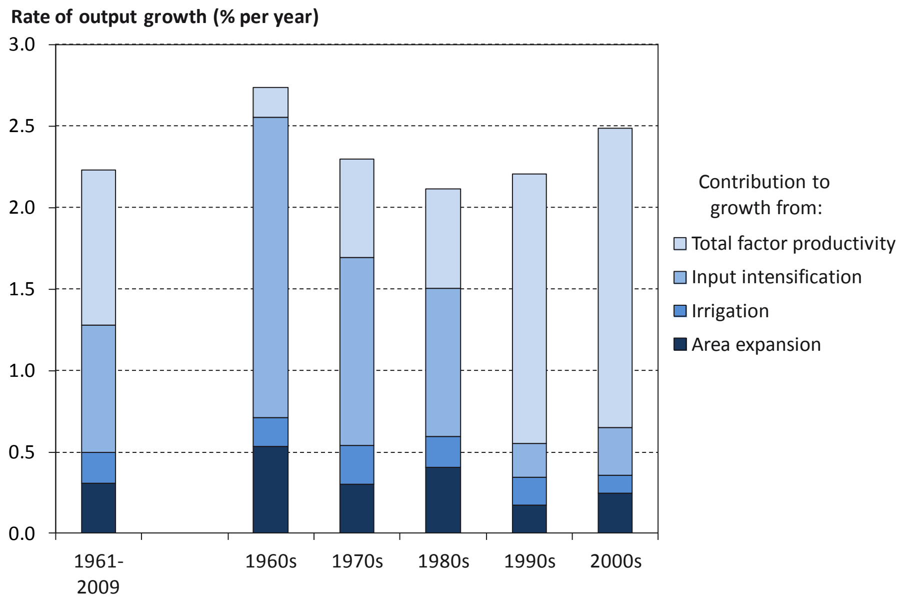

Figure 1-2. Agricultural total factor productivity (TFP) has replaced resource expansion and input intensification as the primary source of growth in world agriculture. The total height of the bar is the average annual gross rate in gross agricultural output over the period, which is partitioned into the four components shown. Source: Fuglie et al.[5]

Indicators such as crop yield or partial factor productivities of land, water, fertilizer, and labor show a less encouraging global picture[20]. Declining freshwater resources, rising energy prices, or low efficiency of nitrogen fertilizer affect many former Green Revolution regions[21]. Recognizing that each country has different staple crops that form the basis for food and nutritional security, a major global concern is the slowing yield growth in cereal crops, particularly rice and wheat that are the basis of food security in many parts of the world[9,22]. During the 1989-2008 period global yield growth rates have averaged 1.6% for maize, 1.0% for rice, 0.9% for wheat and 1.3% for soybean, which is insufficient for meeting future food demand without having to convert a lot more land into agriculture[23]. For comparison, doubling yields over the next 40 years would require annual yield growth rates of more than 1.7%.

Farm yields are approaching their economic upper limits in highly productive areas. In major irrigated wheat, rice, and maize systems, yields appear to be near 80% of the yield potential, with little evidence for having exceeded this threshold to date[24,25]. Further genetic improvement of crop yield potential is

[e] **Total factor productivity** is the productivity of all inputs taken together. It compares growth in all inputs (land, labor, capital, material inputs) with growth in total output of crop and livestock products. It is mainly a measure of technological efficiency and does not account for agriculture's effects on the environment.

difficult and will take decades rather than years to be achieved[9,26]. On the other hand, many improved agronomic practices can still lead to higher yields and/or higher efficiencies and greater sustainability in many farming systems. Rainfed farmers, for example, appear to have relatively large yield gaps (50% or more) that persist largely for agronomic, economic and social reasons[24]. There is also strong evidence for decreasing crop yield growth due to rising temperatures and uncertainty in growing season weather[27]. More broadly, climate change will affect agriculture in many ways, requiring substantial investments in designing and implementing climate-smart food systems (Box 1-1).

Box 1-1. Climate change and agriculture

At present our world is 0.8°C above pre-industrial levels of the 18th century. At current trends 2°C warming could be reached within one generation. Globally, warmer temperatures, changes in rainfall patterns, rising sea water levels, increased frequency and perhaps also severity of extreme weather, and ocean acidification are likely to cause greater short-term variability in the food supply and have long-term consequences for agriculture and food systems. The potential impact is less clear at regional or national scales, but the available evidence indicates that climate variability and change will exacerbate food insecurity and malnutrition in the areas that already suffer most from poverty and hunger and are also most vulnerable to extreme weather at present[28]. Sub-Saharan Africa and South Asia are particularly prone to productivity losses from climate change because major staples in these regions are often already grown above their optimum temperature, with as much as 10% yield loss for +1°C of warming predicted in some locations[27]. Climate change thus directly affects the food and nutrition security of millions of people, potentially undermining progress towards a world without poverty and hunger. It is likely that food inequalities will increase, from local to global levels. Food access and utilization will also be affected indirectly via collateral effects on household and individual incomes, and food utilization could be impaired by loss of access to drinking water and damage to health. The impact of past greenhouse gas emissions cannot be reversed in the next few decades. There is need for considerable, immediate investment in adaptation and mitigation actions that address climate change impacts on all dimensions of food and nutrition security. Each country needs to have a clear climate change strategy for agriculture, including strong commitment to near-term adaptation measures. Many technology, policy and governance interventions must be integrated to move towards a "climate-smart" agriculture (CSA)[28,29]. The whole food system needs to adjust to climate change, with strong attention also to trade, stocks, and to nutrition and social policy options. Despite a massive research literature, much remains unknown about many direct and indirect food security impacts of climate change, including human and agro-ecological dimensions. To enable countries to plan and act will also require significant improvements of data, models and decision tools used for projecting climate change and its impact on agriculture, and for supporting real-time action on the ground[30-32].

In densely populated world regions land and water are becoming scarce resources in agriculture. How much more fertile agricultural land will be lost to urbanization and industrialization in rural areas is difficult to predict. It is safe to assume that those trends will continue in many countries, thus increasing the pressure to produce more from the remaining land. Various forms of land degradation already affect about 20% of all cultivated land and the hundreds of millions of people living there, often coinciding with areas of extreme poverty[33]. Soil erosion, drought, salinization, waterlogging, desertification and other forms of land degradation have spread widely in the past 30 years, particularly threatening ecosystems and agriculture in arid and semi-arid environments. Economic losses associated with land degradation have recently been estimated at US$ 490 billion per year, or 5% of total agricultural gross domestic product (GDP)[34].

Current predictions indicate that less water may be available and more droughts may occur in the coming decades[35]. The world is currently using some 6000 cubic kilometers of fresh water per year, 70% of which goes to agriculture, mostly in Asia (Fig. 1-3)[36]. In dryland regions such as the Middle East and Northern Africa water use in agriculture can reach up to 90% of the available water. Considering that 40% of world food production comes from irrigated systems on only about 20% of the arable land area, more investments in improving water productivity in existing schemes and safely expanding irrigated agriculture will be needed for long-term food security, but with a strong emphasis on policies and new technologies that ensure maximum efficiency and protect critical freshwater resources[37,38]. Unsustainable depletion of aquifers has become a major concern in some of the largest food-producing and -consuming countries (China, India, USA), but there are also many aquifers worldwide that could still handle further expansion of irrigation[39]. During the Green Revolution in Asia contributions from expansion of irrigated area were at least as large as those from improved varieties, fertilizers and other intensification measures. It is unlikely that Sub-Saharan Africa can achieve a much higher level of food security and sovereignty without more irrigated agriculture. Integrated solutions will need to balance the use of surface water and groundwater resources by different sectors[40], while increasing water productivity in the whole food system. For example, consuming less water can also be achieved through wasting less food, consuming less water-intensive food, and improving water use efficiency in crop-livestock systems as a whole, from forage production to meat consumption.

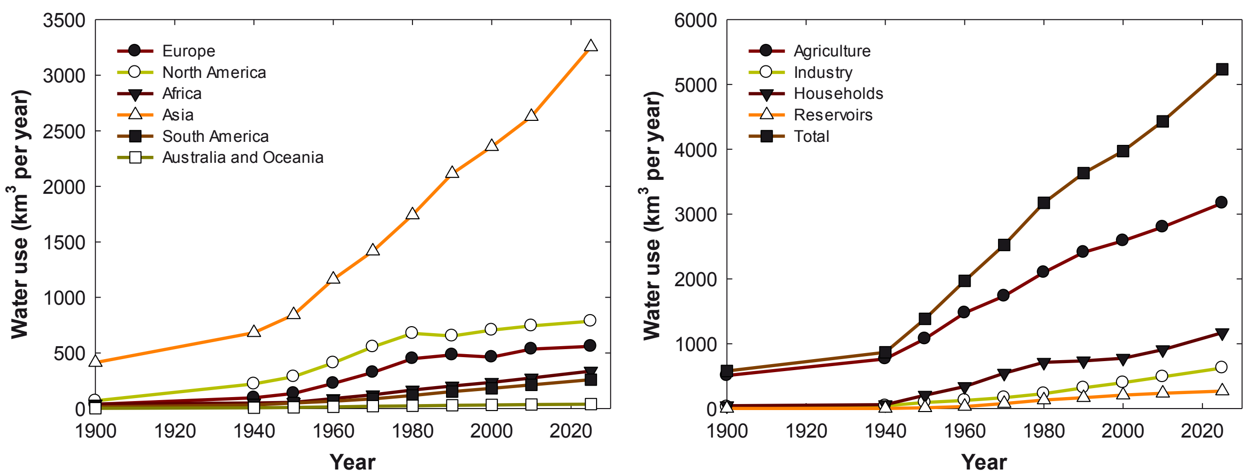

Figure 1-3. Global freshwater use by regions and sectors. Source: UNESCO, I. Shiklomanov

Modern food production depends on fossil fuels and fertilizers, but the planet's nitrogen and phosphorus cycles are out of balance: excessive or otherwise inappropriate nutrient use is causing environmental problems in some regions, while nutrient deficiencies and insufficient fertilizer availability prevent productivity increases in other regions[41]. In Sub-Saharan Africa in particular, continuous cultivation without such fertilizer leads to widespread soil nutrient mining and traps people in poverty[42]. Such regional imbalances and different contexts need to be addressed in defining successful strategies for better nutrient management. Increasing sustainability will demand a push towards both access to fertilizers and greater efficiency in nutrient use. Significant opportunities exist to increase nutrient use efficiency and thus also reduce GHG emissions through full life cycle approaches in the contexts of integrated use of both organic and inorganic fertilizers[43]. Globalization of the food system has also created massive nutrient and virtual water flows of traded agricultural commodities across regions, which also need to be considered when developing new solutions for sustainable use of nutrients and water resources[44]. The nutrients imported are commonly concentrated in cities, creating waste disposal problems rather than alleviating deficiencies in rural soils.

Some 17 billion animals in the world utilize substantial amounts of natural resources, mostly in the developing world, where most of the growth of the sector will occur[45]. Common global concerns about intensive livestock production include overgrazing, costs and environmental consequences of global trade of feed and meat, pollution due to livestock waste, transmission of diseases, animal welfare and large emissions of greenhouse gases, particularly methane. The productivity and nutritional services of extensive livestock systems will need to be boosted substantially in many regions, including crop-livestock systems that enable better utilization of the available resources[45]. Grasslands occupy 40% of the world's land surface (excluding Antarctica and Greenland) and support extensive nomadic as well as intensified livestock-production systems. Nearly 1 billion people living on less than 2 dollars a day in South Asia and Sub-Saharan Africa keep livestock. For many, these animals are their most valuable asset and income source. Many grazing lands are in a degraded state, particularly in marginal areas of developing countries, affecting productivity, household incomes and environmental services such as hydrology, biodiversity, and carbon cycles. Grassland management practices can be optimized to result in positive outcomes for grasslands, the environment, and households[46]. Pastoral communities are among the most marginalized, living in remote areas with poor infrastructure and communication. They often lack access to markets and input supplies and are dependent on their animals to support them. The development challenge for these communities is how to reduce their vulnerability and increase their resilience in the face of external shocks such as drought, which can devastate their herds and livelihoods. Both short and longer term interventions are required for these areas, including rangeland and herd management, early warning systems, social safety nets, livestock insurance programs, timely disaster responses, better education and ensuring political stability[47,48].

Fish are a rich and often cheap source of protein and nutrients for the poor. Aquaculture's contribution to fish supply for human consumption will soon exceed that of wild capture fisheries. Aquaculture has grown at record pace in recent years and it has been a major factor in annual fish consumption reaching an average of 18.6 kg per person in 2011[49]. Growth is driven by increasing demand from a growing urban middle class as well as by technological changes that have increased productivity and lowered prices and volatility. However, for countries most dependent on fish to meet the nutritional requirements of their population, wild capture fisheries remain the dominant supplier, particularly for the poor. FAO - mainly relying on the opinions of regional experts - estimated that about 30% of world fish stocks were overexploited, depleted, or recovering in 2009[49]. Inadequate reporting in official statistics of the small-scale fishing sector in developing countries likely leads to underestimates of global marine and freshwater catches. Others have estimated that 80% of global stocks of over 500 fish species are fully or over-exploited[50]. Although not all fisheries are in crisis, securing the sustainability of global fisheries is essential and requires innovative efforts across a broad spectrum of fishery systems[51].

Poverty alleviation, economic and social rural development

The first MDG of eradicating extreme poverty and hunger was in many ways the most ambitious and the most difficult to define in terms of implementation strategies. The goal of halving the proportion of people whose income is less than $1.25 a day was met five years ahead of schedule, primarily due to the extraordinary economic growth rates in East and Southeast Asia, and the associated structural transformation of those economies. Progress in South Asia and Sub-Saharan Africa was limited and most of the billion people who remain below the poverty line live in rural areas in those two regions. Reducing rural poverty still remains one of the more difficult development challenges because it requires sustained, socially inclusive economic growth, particularly in the agricultural sector. Clear strategies to generate broad agricultural growth in Sub-Saharan Africa are needed. Farm sizes are shrinking due to population increase as well as current land tenure systems in densely populated areas, while there is continued reliance on area expansion where populations are sparse. Reliance on market mechanisms only may contribute to inequality in rural income distribution, as efforts to increase farm productivity, improve access to markets, and subsidize inputs may favor farmers with sufficient land and capital resources. Other policies can contribute to inequality by favoring those with legal tenure over those without, male farmers over female, ethnic majorities over minorities or nomadic peoples, and farmers living closer to population centers and markets over those living in the most rural areas.

In South Asia rural poverty tends to be concentrated in lagging areas that have not been integrated into the larger economic growth process. In Sub-Saharan Africa, particularly in countries that lack major mineral resources, the agricultural sector is the largest employer and contributes significantly to overall economic growth. Between 2010 and 2050 the rural population in East Asia is expected to decline by 50% and by 10% in South Asia, but is likely to increase by about 30% in Sub-Saharan Africa[52]. Annually, some 10-15 million young people will be looking for jobs in these rural areas. Although this increases the pressure on natural and social resources, it is also an opportunity for vibrant rural development. Igniting a structural transformation towards sustained and sustainable growth in smallholder productivity in Sub-Saharan Africa remains one of the dominant development challenges into the medium-term future.

Rural households in many countries obtain half or more of their income from non-farm sources. Facilitating the diversification of off-farm income sources for rural people will play an important role in building resilience and food security for rural families. Policy support for the establishment of small-scale food processing industries in rural areas could contribute to reduced losses, increased food quality, smoothing of consumption and the reduction of drudgery.

Small farming businesses are hugely important for the sustainable food systems of the future, but many of them are left behind because, unlike large farms, they lack land resources and other capital or have poor access to markets and functioning extension services, even in many industrialized countries[53]. Some 1 to 2 billion people live on land for which they have no legal title, preventing them from obtaining credit and investing in productivity-enhancing measures[8]. Female smallholder farmers comprise about 50% of smallholders in Eastern and Southeastern Asia and Sub-Saharan Africa. They typically face more challenges than their male counterparts, but they represent a huge, underutilized potential. It has been shown that women farmers who have the same access to productive resources as men could increase yields on their farms by 20-30%[54].

The trends of rapid urbanization and the vanishing rural labor pool have huge implications for the future of small-holder systems in which abundant labor is needed for field work, tending livestock and nutrient recycling[55]. New models for consolidation of farms or farm operations and services will be needed in many areas, also to allow for greater mechanization. Broad investments in rural infrastructure, inclusive entrepreneurship models, strengthening of local capacity to customize best management practices, and other social innovations are needed to transfer more value to smallholder farmers, minimize risk, and provide a safe operating environment for them.

Food systems for nutritional security and better health

Achieving food and nutritional security requires every member of society to have access to nutritious food and the information and freedom to make appropriate choices concerning good nutrition. Progress has been made in reducing undernourishment, underweight, child stunting, child mortality, and micronutrient deficiencies. But progress has varied among countries and setbacks are common due to volatile food prices, conflicts and natural disasters. Currently, about 870 million people (12.5%) are chronically undernourished in terms of energy intake and about 2 billion people suffer from vitamin and mineral deficiencies[6,56]. Malnutrition[f] — resulting in fetal growth restriction, underweight, stunting,

[f] **Malnutrition =** an imbalance between nutrient intake and nutrient needs for an active, healthy life, which may involve over- or under-nutrition by a variety of conditioning factors. **Undernutrition** = insufficient nutrients for an active, healthy life, often observed during gestation and infancy and among adolescent girls and women whose specific nutritional needs are least likely to be met by the family diet.

wasting, and deficiencies of vitamin A and zinc and suboptimum breastfeeding —causes more than 3 million child deaths annually (or 45% of all child deaths in 2011)[57]. Stunting has surpassed underweight as the most prevalent nutritional challenge, affecting 165 million children worldwide, or one in 4 children under the age of five[57,58]. Overcoming malnutrition during the first 1000 days of life, from conception until age 2, is among the most critical interventions needed, for which agricultural strategies can provide solutions.

The growing new challenge is that two thirds of the world's population live in countries where overweight and obesity kill more people than underweight. Some 1.4 billion adults and 40 million children under the age of five are overweight, including 500 million who are obese[59]. Maternal and childhood overweight and obesity are becoming an increasingly important contributor to adult obesity, diabetes, and non-communicable diseases[57]. Inequalities are increasing within countries, requiring new policies to address both overweight and undernourishment at the national level. In rapidly growing countries such as China or India a wealthy, urban, and more obese population coexists with a poor, rural, undernourished one. Multiple forms of malnutrition may occur in the same families or individuals. Those that are undernourished often have insufficient resources to make food choices and are often also in a situation where there are environmental disasters or social unrest and thus unable to gain access to sufficient, quality food. Those that are overweight often have more resources but make poor food choices, leading to obesity and the associated non-communicable diseases which can put a very heavy load on medical and support services. A new phenomenon is that people may be exposed to deficient diets in early life but are at heightened risk of becoming overweight later in life[57].

Generally speaking, people who are fed properly are healthier, but nutritional and health linkages differ widely. For example, the stunting and wasting of under five children which is widespread in rural areas of South Asia and Sub-Saharan Africa is an entirely different problem than the increasing obesity or concerns about food quality and safety in rapidly urbanizing populations. It is broadly accepted that an adequate and balanced diet provided through effective agricultural production results in healthier children and communities. The relationship between agriculture and nutritional outcomes is mediated by access to food, women's and youth education, cultural habits, health status and the health and sanitation interventions that allow vulnerable children to take advantage of dietary improvements. Systematic efforts to explore these linkages are still rare and the results are not always clear[60].

Needs for dietary changes for improved health and nutrition vary. In most low-income countries modest increases in consumption of animal source foods can contribute substantially to ensuring dietary adequacy, preventing undernourishment and improving nutritional deficiencies. On the other hand, if high-income countries continue to consume more meat and sugar and middle income countries follow a similar path, health risks as well as pressure to grow more crops for animal production would increase to levels that could be difficult to manage. Horticulture, on the other hand, is likely to make a positive contribution to nutrition via income and diversified consumption in all countries.

Agriculture-health linkages also include food-borne and animal-transmitted diseases or water- and vector-borne communicable diseases related to the management of agroecosystems. Mycotoxins - substances naturally produced by molds and microfungi that are capable of causing disease and death in humans and animals[g] - have emerged as a major global concern[61,62]. High levels of mycotoxin infections are mostly caused by stress on the plant grown in the field, delayed harvest and poor storage of grains, thus also resulting in negative economic impact for farmers. Moreover, in less developed countries more

[g] For information on mycotoxins see www.knowmycotoxins.com

than 10% of the infectious disease burden is due to zoonoses[h], and the majority of them are transmitted to people from livestock hosts through consumption of animal source foods, vectors or direct contact[45]. The growing densities of human and livestock populations, especially in South and East Asia, are increasing the probability of new zoonotic diseases[63]. Agricultural intensification and/or environmental change are associated with an increased risk of zoonotic disease emergence, driven by the impact of an expanding human population and changing human behavior on the environment[64].

1.2. Risks under a Business-As-Usual scenario

In the absence of change towards a new, shared global framework for sustainable development of agriculture and food systems, a Business-As-Usual (BAU) trajectory would have severe implications for food and nutritional security, economic and social development, public health as well as environmental sustainability. In a scenario of continuing current trends world cereal production would increase by 52% from 2010 to 2050, whereas world meat production rises by 64% (Annex 1)[65]. Although positive efforts are already underway in some regions and countries, they are not sufficient yet to enter a sustainable development path for agriculture. Some countries will be less negatively affected than others under a BAU scenario, but the vast majority will be worse off (Table 1-1; Box 1-2).

Table 1-1. Regions likely to suffer moderate (M) and high (H) costs in the Business-As-Usual scenario of unsustainable agricultural development.

	North America	Latin America & Caribbean	Europe	Middle East & North Africa	Sub-Saharan Africa	South & Central Asia	Southeast Asia & Pacific	East Asia
Food insecurity				H	H	H	M	M
Malnutrition					H	H	M	M
Obesity, health	H	H	H	H		M	M	M
Poverty				M	H	H	M	M
Poor rural infrastructure		M		M	H	H	M	M
Conversion of natural land		H			H	M	M	M
Soil and land degradation				M	H	H	M	H
Water shortage	M			H	H	H	M	M
Water and air pollution	M		M	M		H	H	H
Biodiversity loss	M	H	M	M	M	M	H	H

<u>Notes on Table 1-1:</u> Each row in the table is based on a general assessment of current levels and future trends, for which the authors reviewed available data and projections. We underscore the illustrative nature of the results.

[h] Zoonotic diseases are those that evolve in animal populations but are transmitted to humans.

Box 1-2. Examples of major risks that could arise in the BAU scenario

Food and nutritional security

- High food prices will put a drag on economic growth.
- Agricultural productivity growth and access to food will be insufficient to eradicate extreme hunger and nutritional deficiencies in a growing population by 2030 or even 2050.
- Volatile food markets and prices, and little ability to absorb supply shocks caused by climatic extremes, natural disasters, economic constraints, political unrest, and competition with biofuels.
- Many countries will continue to have unexploited yield and efficiency gaps and rely heavily on food aid and imports.
- Continued large food losses and waste; eroding public trust due to frequent food quality scandals and diseases caused by unsafe processing and handling of food.
- An excessive focus on staple productivity exacerbates the problem of micronutrient deficiency. Persisting malnutrition in mothers results in the next generation not being able to fulfill its human potential.
- Increasing obesity problems due to unhealthy diets and emergence of numerous associated health problems.

Economic and social development

- Agricultural productivity growth will not be sufficient to eradicate rural and urban poverty. Due to volatile food prices, tens of millions of people will swing between being lifted out of poverty and being thrown back into it.
- Social, economic, and political stability is at risk due to large regional, national, and within-country nutritional and food distribution gaps as well as competition for natural resources.
- People and countries may fight over land, water, and some mineral nutrient resources, particularly countries that do not own such resources.
- Smallholder farmers and local agricultural businesses will continue to lack access to markets and financial resources, and thus are not able to overcome the poverty traps associated with small holdings and/or poor soils. They will be unable to benefit from new technology. Farming families will be left behind in the economic and social development taking place in urban areas.
- Gender asymmetry in access to assets and economic services continues.
- Farmland prices will rise, making it difficult for young people to enter farming.
- Lack of roads, clean water and electricity will continue to make it impossible to significantly improve the lives of the rural poor.
- Youth unemployment in rural areas will further rise. More young people will leave the countryside and move to the city, accelerating urbanization.
- A less mobile, aging workforce will be left behind in the villages.

Environmental sustainability

- Global fertilizer production will increase by another 40-50% by 2050 to feed the growing population and its dietary lifestyle. If not managed correctly, the increase in fertilizer production may have unwanted environmental impacts.
- Faster depletion of water resources used by agriculture may lead to reduced access and/or higher prices.
- More forest, wetlands and other land could be converted to agriculture, further increasing greenhouse gas emissions.
- Degradation of existing agricultural land may increase further. Soils in developing countries would become even more depleted of carbon and nutrients, particularly in Sub-Saharan Africa.
- Excessive or otherwise inappropriate use of agrochemicals in agricultural systems could cause more water pollution and loss of species diversity, particularly of insects and their food webs.
- Unsustainable depletion of many fish stocks will continue.
- Declining diversity and species habitat quality in agricultural landscapes could reduce ecological resilience and increase the vulnerability of agriculture, particularly in fragile environments.
- Progress in sustainability reporting and stewardship system development by a variety of stakeholders will continue, but at a relatively slow pace.

In many countries, a BAU scenario would also mean a continuation of dependence on foreign aid investments in agriculture as opposed to governments and private sector making their own investments and policy reforms that create an enabling environment for broad-based economic development. Lack of long-term strategy, commitment and coordination would continue to dominate investments in agricultural research and development, slowing progress in much-needed innovations.

The BAU scenario is clearly not a sustainable development path because food prices would rise further, poverty and hunger could not be eradicated, poor food choices in both rich and poor countries would continue, and environmental pollution, loss of forests and biodiversity, and degradation of land and other natural resources would accelerate even further. Many countries would not be able to achieve their economic and social development goals (Box 1-3).

Box 1-3. The role of the smallholder in the structural transformation of Kenyan agriculture and economy

Kenya is poised to embark on a sustained economic growth path of at least 5% per annum that could move it into the status of a middle income country within 20 years. The locus of the economy will shift from its agrarian roots to one that is more urbanized, industrial and service-based. Kenyan economic development faces a number of challenges, many of which have their origin in the health of the smallholder farm economy. Kenya has rapidly urbanized, from less than 9% in the 1960-70 period to over 20% at present. Over half of the urban population is absorbed in informal employment and settlements. Despite two decades of growth, structural adjustment and poverty reduction plans, rural poverty rates have remained consistently high at over 40%, with significant regional differences. About 80% of agricultural production comes from Kenya's 2.9 million smallholders, yet only 30% of them are net sellers of maize, whereas 10% of larger farms account for 75% of maize marketable surplus. Farm productivity is increasing but it is not sufficient to improve incomes and in several high population density regions farm size is now limiting sustainable intensification.

Balanced structural transformation of the economy is dependent on a number of processes driving structural change of the agricultural sector, namely (1) increasing marketable surpluses through formal supply chains, (2) rising land and labor productivity in agriculture, (3) rural livelihood specialization, in which agriculture becomes the key economic activity of fewer, more professionally managed farming households, (4) the development of efficient input and output markets, and (5) eventually an increasing average farm size. Kenyan agriculture is far from achieving these outcomes and is particularly constrained by declining farm size, in many areas below an asset base that will allow a realistic pathway out of poverty. At the same time smallholder farming systems themselves must intensify, often with significant change in the mix of production activities, farm management, and improved market integration. Structural transformation thus involves change at three different levels, namely the flow of goods, labor and investment capital in the overall economy; the change in markets, institutions, infrastructure, and supply chains within the agricultural sector itself; and the response at the level of the farming system as it intensifies and engages increasingly in the market.

Although, compared to the BAU scenario, any scenario of accelerated productivity growth would help with reducing poverty and hunger, productivity and efficiency increases alone will not be sufficient to achieve all of the targets of sustainable agriculture and food systems, including better environmental stewardship, protection of natural resources, and healthier human beings. More radical transformations of food systems will be required, but without neglecting the basic need for broad productivity growth as the fundamental driver for eradicating poverty and hunger.

2. Towards a sustainable development path for agriculture and food systems

Population and income growth are the major drivers for agriculture. A sustainable development path will require decisive and ultimately transformative changes of the global agriculture and food system to increase food availability and utilization, improve the environment, make human beings healthier, and create more prosperous rural communities. Although opinions may differ about the specific solutions to pursue, a consensus is emerging that measures to be taken must address food demand, production, consumption and losses[3,6,9,11,11,17,19,19,20,66-75]. Management of population growth, food losses and waste will be important for reducing the pressure on agricultural land, water and natural ecosystems, in addition to increases in agricultural productivity and efficiency and measures to protect natural resources from unsustainable exploitation, degradation or pollution[11,66,76].

Transformative changes of agriculture and food systems are needed in all countries, but the priorities differ. Eradicating poverty and hunger and accelerating rural development are the highest priorities in low-income countries. Both require broad-based agricultural productivity gains. More generally, broad global productivity growth is important for keeping world food prices low enough to combat poverty and hunger, but also to curb food and bioenergy-driven expansion of agriculture into natural ecosystems. Future growth in food production needs to be decoupled from recent trajectories of inefficient and unsustainable use of primary resources.[i] This will require increasing the efficiency of complete food chains and changing the behavior of all actors involved, including policy makers, businesses, consumers and farmers. The consumption models that have dominated economic development in richer countries during the past five decades also need to change[77]. Food safety standards need to be raised for major food production and processing chains worldwide[j], but also in live animal and wet food markets of many developing countries.

Many interventions are needed, but due to different starting points and many barriers that need to be overcome not all can be implemented in the same order of priority and at the same speed everywhere. Changing diets towards healthier, less resource-intensive foods and reducing food waste are likely to be difficult and uneven processes. The priority on the supply side is to increase production on existing crop land. This can be achieved by closing yield and efficiency gaps and, where possible, diversifying and increasing the number of crops grown per year, as well as reducing pre- and post-harvest losses. Although there is still suitable land that can be developed for agriculture, a fundamental question is how much of that land should be taken under cultivation or whether future food demand can be entirely met without bringing more land under cultivation. For livestock, the challenge is to increase productivity per animal through better feeding, effective animal breeding and livestock health care, and where possible shifting to more efficient animals, such as from cattle to poultry and fish or small ruminants.

The transition to sustainable development pathways for agriculture will require all stakeholders in the food system to adapt and adopt state of the art knowledge and technologies, and it will require trying multiple models. Ideological battles over whether it is right or wrong to eat meat or whether agriculture should be “conventional”, “GM”, or “organic” can lead to inconsistent and inefficient outcomes, particularly when local contexts are ignored in sweeping campaign rhetoric. To feed and green the world

[i] Decoupling means an increase in the use efficiency of primary resources and reduction in pollution as agricultural growth proceeds, through a combination of new technologies, policies and economic incentives for individuals, businesses, and governments.

[j] See www.who.int/foodsafety/en for an overview of the key issues and measures.

means to support the dynamic evolution of farming systems more strongly by providing farmers with necessary information, inputs, and recognition. There is no revolutionary alternative. Proposals to transform agriculture to low-input and organic systems would, because of lower productivity, exacerbate the global food and nutrition security challenge[78].

Farms of different sizes and commercial orientation coexist in any location, and further differentiation over time is driven by the interaction of demographic and economic change. In terms of commercialization, while many hinterland farms continue to face high transaction costs and therefore remain largely self-sufficient, farms closer to markets are becoming increasingly specialized and linked to agribusinesses[55]. In terms of farm size, the momentum of population growth will continue to drive declining total land area per farm across Africa for many more years, with corresponding reduction in natural resources available per farm family. The land available per farm will continue to shrink until non-farm opportunities expand enough to absorb all new workers entering the labor force. Asia as a whole has already passed this turning point so its average farm sizes can rise, compounding the opportunities afforded by increased commercialization[55]. The resulting interlinked transformations of the agrifood system from urbanization include changing diets, food markets, rural factor markets and agricultural technologies as well as farm size[79]. While recognizing the huge importance and potential of smallholder farming for current and future agriculture[80], we also have to accept that for many small farmers and their families the best roadmap for development is to move out of farming. Non-farm rural and urban employment opportunities will drive this process. For those who remain in farming this will provide new opportunities to increase productivity and income, and use resources more efficiently.

These trends have huge implications for agricultural policies, rural development, and research. The world needs to concentrate its efforts on science-based, actionable solutions that are tailored to local situations and support structural transformations of the whole food system. New business models for farming and new approaches for providing access to modern agricultural technology to all farms at different scales are needed to ensure a sustainable development path. Good governance and support mechanisms must ensure fair access to resources, new markets and innovative technologies. Policy makers, scientists, agricultural professionals from all sectors and farmers need to be equipped with the right knowledge and information. Basic education and vocational training will play an important role. It is only through education that we can provide every child the chance to escape poverty in rural areas, and that we can change the behavior of food consumers towards healthier diets, less food waste and a greater understanding and acceptance of agriculture and new technologies.

2.1. Reducing food losses and waste and shifting to healthier diets

Healthier diets[k] and less food loss and waste must be integral components of future sustainable food systems. Given the diversity of causes involved, solutions for that need to be flexible, targeted, and applied in a local context, with strong government leadership at all levels as well as participation by all key actors along the food chain, including the food industry. Greater coordination among agriculture and health extension workers would be beneficial.

[k] A **healthy diet** provides nutrients in the proportions needed for bodily function and development, with sufficient quantities of essential nutrients and limited exposure to harmful substances. Nutrient needs vary over time and across people, and include adequate fluid and total calories, protein and fats, as well as a range of vitamins, minerals and other micronutrients. These needs can be met from a variety of plant-based and animal-based foods, in proportions tailored to each person's activity levels and developmental circumstances.

Urbanization, the commercialization of food systems and the globalization of food trade have changed the way food is supplied and consumed. The movement towards increased consumption of simple and refined carbohydrates and excessive saturated and trans fats is causing a decline of dietary diversity[81] and health among the poor and rich alike[82]. These foods also have a higher energy intensity during production, leading to increased consumption of land, water, energy and nutrient resources[41]. Shifting to plant-based protein and more diverse diets would be beneficial for human health and resource use efficiency in many regions, but there are important exceptions to consider. Ingrained cultural patterns related to the consumption of animal products, fat, salt, and refined foods, for example, necessitate a nuanced approach to the pursuit of healthier diets. For example, in fragile regions the most sustainable way of farming and livelihood is through grazing animals and consumption of their products. Hence, intervention strategies need to be based on culturally-variable definitions of what is considered "healthy". In many countries they will require focusing on inappropriate quantities and quality of our food choices, compounded by other unhealthful lifestyle choices. In other countries they will have to also address other issues, including improving the traditional farming systems to enable healthier diets.

It has been estimated that - on fresh weight basis - as much as one third of all food grown[l], some 1.3 billion tons per year, may be lost or wasted[83,84]. When converted into calories, this means that about one out of every four calories grown is not ultimately consumed by humans[85]. The economic value of food losses in affluent countries appears to be in the range of 0.5 to 1% of GDP, but in many developing countries, where food forms 20-40% of GDP, the food loss equates to 7-15% of GDP[41]. Environmentally, food loss and waste inflict a host of impacts, including unnecessary greenhouse gas emissions and a waste of water and land resources[85].

Crop losses are often associated with the earlier stages of the food chain (i.e., pre-harvest, harvest and postharvest losses), whereas food waste mainly occurs at the market, retail and consumer ends. Decreases in food and nutritional quality due to poor harvest, storage and processing also negatively affect the income realized by sellers and health of consumers. In developing countries, ineffective pest and disease management, poor harvest practices, poor storage facilities and inadequate infrastructure mean that large losses occur during and after harvest – between farm and market. In developed countries, and increasingly in developing countries, there are substantial losses in the processing, packing, and distribution stages, compounded by legislated 'due date' restrictions, and also waste in the home and restaurants. The latter is increasingly becoming a problem in developing countries, particularly in urban areas. Food distribution and consumer behavior play a major role; information and awareness is needed as well as better technologies to manage food marketing.

By how much food losses and waste can realistically be reduced remains unknown. There is also no evidence that if the food loss was prevented, those who need more food the most would have access to the rescued food. Nonetheless, for the hundreds of millions of smallholder farmers who are substantially self-provisioning and market their surpluses, reducing their losses would increase consumption and income. As a general strategy, developing countries should increase their investments in reducing postharvest losses, whereas developed countries should create entities devoted to reducing food waste[85].

The task of tackling the problem of food loss and waste is also bedeviled by lack of data. Historically, given the technologies and methods available, the cost of measurement has tended to exceed the benefits of obtaining those measurements. FAO has only recently started to assess food losses and

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[l] FAO estimates global losses (on fresh weight basis) of about 30% for cereals; 10% for oilseeds and pulses; 40-60% for root and tuber crops, fruits and vegetables; and 20% for meat, dairy, and fish. However, the quality of the underlying data is generally uncertain. Actual losses vary widely and are likely to be lower in many food production systems.

waste by region and food type. This work is important because once countries, companies and individuals know both the extent of food waste and location in the value chain it is easier to identify and take steps to address the problem. The degree of financial loss caused by food waste needs to be communicated clearly to all stakeholders, including consumers. The food system is unlikely to grow less complex. Therefore, innovative new techniques and methods need to be aggressively developed to know *how much food loss and waste can realistically be prevented.* Digital technologies have many applications in postharvest loss and food waste tracking and prevention, and will also serve to deepen actor and stakeholder understanding of the complex nature of the supply chain. With this understanding, interventions can be carefully assessed and targeted to ensure losses are prevented sustainably and effectively.

Many successful interventions would require substantial investments in infrastructure and improved technology. Reductions of postharvest losses often require significant capital investment to improve storage and transportation systems. However, many less costly technologies can also help reduce losses at different stages of the food chain, including packaging for portion control at pre-consumer stage; breeding crops with longer shelf life; using micronutrient-enriched fertilizers with boron, known to prolong the shelf life of fruits and vegetables; improving harvest practices; and low-cost drying and hermetic storage solutions.

2.2. Producing more food through sustainable agricultural intensification

A consensus is emerging that addressing the new challenges requires a **Sustainable Agricultural Intensification (SAI)**[m] in small and large farms throughout the world[86-89]. A simple operational definition of the objective of SAI is to provide sufficient, accessible, nutritious food, while enabling economic and social development in rural areas and treating people, animals and the environment with respect. Key premises of SAI include[89]:

- The need to produce more food, and more nutritious food.
- Increased production primarily through higher yields, to limit conversion of forest, wetlands or grasslands to agriculture.
- Re-thinking and transformative changes of food systems to achieve greater resilience and major reductions in environmental impact.
- Formulation of context-specific strategies and solutions for SAI that are integral components of accelerating economic and social development in rural areas.

In practical terms, this primarily means to *deliver more product (food and other agricultural goods) per unit of resource, whilst preventing damage to natural resources and ecosystem services that underpin human health and wellbeing both now and in the future*[76]. Depending on the context, improved performance may mean any or all of the following: increased profitability and productivity (agricultural outputs such as food, feed, fiber, and biofuels), high efficiency and returns from external inputs, improved crop and livestock yield stability, reduced greenhouse gas emissions, enhanced ecological

[m] Sustainable agricultural intensification is the efficient production of safe, high quality agricultural products, in a way that protects and improves the natural environment, the social and economic conditions of farmers, their employees and local communities, and safeguards the health and welfare of all farmed species (www.saiplatform.org). SAI is an evolving concept and definitions of it vary. Other terms proposed in the literature include, for example, sustainable intensification, ecological intensification, eco-efficient agriculture or agro-ecological intensification.

resilience, better animal welfare, and environmental service provision (e.g., clean water, flood protection, recreational and cultural landscape values).

Not all of these outcomes can be achieved at once or simultaneously everywhere. Trade-offs among different outcomes are often required to achieve SAI[76]. High priority must be given to helping farmers worldwide adapt to climate change and weather extremes by building more resilient agricultural systems. Otherwise, world food security will be at tremendous risk and other development goals cannot be achieved[28]. Agricultural labor productivity is of fundamental importance to economic growth, poverty reduction and food security and must receive sufficient attention when setting the goals and strategies for future, sustainable agriculture[15]. Simply speaking, SAI aims to reduce the environmental footprint of agriculture while meeting all of its other goals. That requires making farming more precise by implementing genetic, agro-ecological, as well as socioeconomic intensification measures, and having the necessary support systems in place for maximum impact (Fig. 2-1)[86].

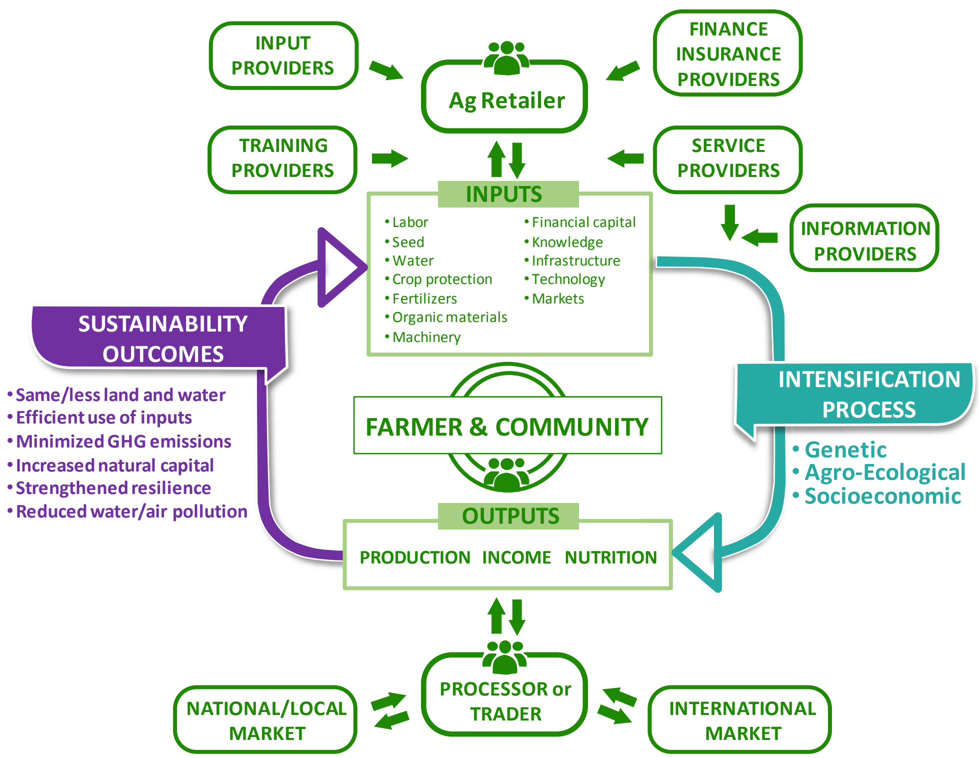

Figure 2-1. Sustainable Agricultural Intensification and its enabling environment.
Source: Modified from The Montpellier Panel[86].

In practice, workable options - actionable "solutions" - must focus on raising the diversity, productivity, efficiency, resilience, value and therefore also the overall profitability of farming. This is the entry point for moving from the vicious circles trapping rural people in poverty or creating environmental problems towards virtuous circles of agriculture for sustainable development (Fig. 2-2). It requires flexibility to adapt to new information and the recognition that the information upon which one takes initial action may, in retrospect, be misinformation. Sustainability will necessarily require trial and error, i.e., adaptive approaches on a grand scale. One of the chief hurdles will be to deal with resistance to change.

Raising productivity has additional benefits to those listed above; it is also an entry point for creating jobs and entering new domestic and export markets. If done properly, productivity- enhancing technologies reduce the unit cost of food production as well as the ecological footprint per unit food produced. They lead to a supply shift and thus reduced equilibrium market prices for commodities. The reduced lower prices positively affect food and nutritional security and reduce poverty. But lowered prices also reduce the profitability of expanding cultivation into marginal areas, thus reducing the demand and the incentives for agricultural incursion into remaining natural ecosystems. This in turn results in positive consequences, such as better conservation of biodiversity or less emissions of carbon stored in aboveground vegetative biomass or soils of natural ecosystems. The virtuous circle can be greatly accelerated through efficient support systems: e.g., policies, infrastructure, markets, research and development, human resources, digital information, and other tools.

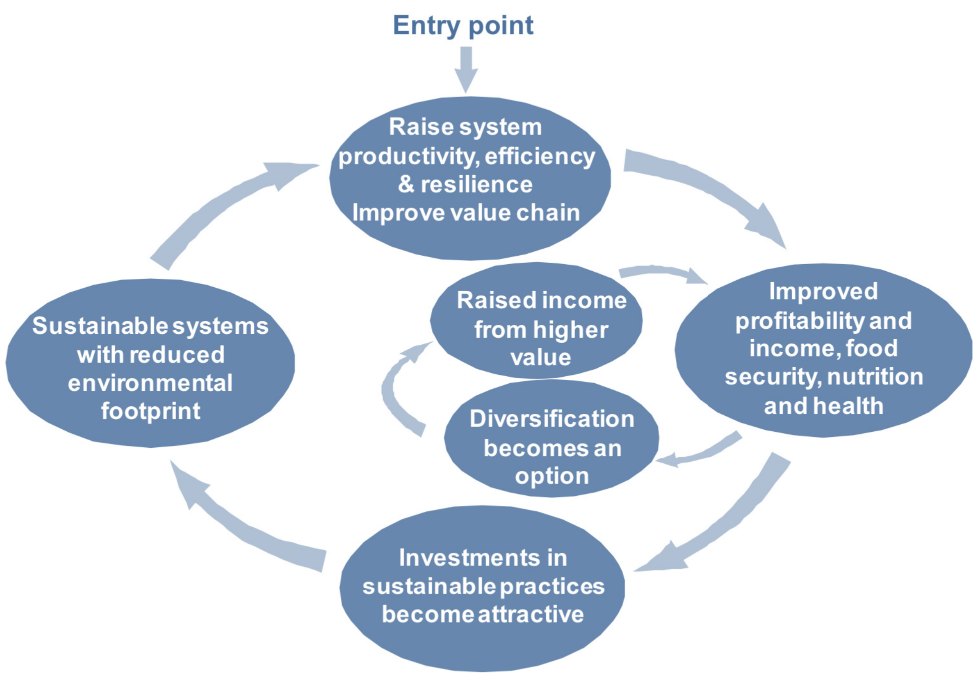

Figure 2-2. Enhancing system productivity and value is the entry point for enabling farmers to enter a virtuous circle of sustainable agricultural production and livelihood. Source: Modified from IRRI[90].

Among the greatest challenges for agriculture is to boost crop yield growth rates to levels that would allow feeding the growing world population a healthy diet primarily through increased production growth on existing agricultural land. In most low- and middle-income countries diversification of cropping systems and/or conserving more land can only happen if yield growth in cereals and other food staples can be accelerated. How fast yields need to grow depends on the overall trajectories of food demand in a country, how much more land could safely be utilized for agriculture, or to what extent cropping intensity on existing land can be increased. Food production projections by FAO assume an annual global crop yield growth rate of only 0.8% during 2005/2007 to 2050, whereas arable land area would expand by more than 70 million hectares during that period[18]. However, if arable land expansion is to be halted completely, global yield growth rates have to be accelerated substantially. One target of sustainable agriculture should be to ensure that annual yield growth of the world's most important staple crops rises as fast as or faster than the demand by closing existing productivity gaps and raising the yield ceiling. Ensuring food security in the 2015-2030 period with minimum expansion of agriculture would require that yields of the major cereal crops increase by about 1.3-1.5% each year. Growth in major food staples cannot be compromised, but countries should also take other measures, including feeding less grain to cattle or using them as biofuels, and enhancing the productivity and adoption of legumes and other crops of local importance.

To define the right SAI strategy in a country, a precise understanding of yield, efficiency and/or product quality and value gaps, i.e., how large they are, where they occur, and what their biophysical and socioeconomic causes are, is needed at sub-national and local levels.[n] Progress has recently been made in establishing better methodologies for yield gap analysis, mapping the yield gaps of major crops at global and regional scales, and understanding their different contexts[92-96]. Although this is encouraging, a lot more remains to be done to obtain a deep understanding of yield and efficiency gaps in the world's major agricultural systems, at a scale that enables people to use this knowledge for concrete action in farmers' fields. Similar methodologies need to be applied to quantify livestock productivity gaps.

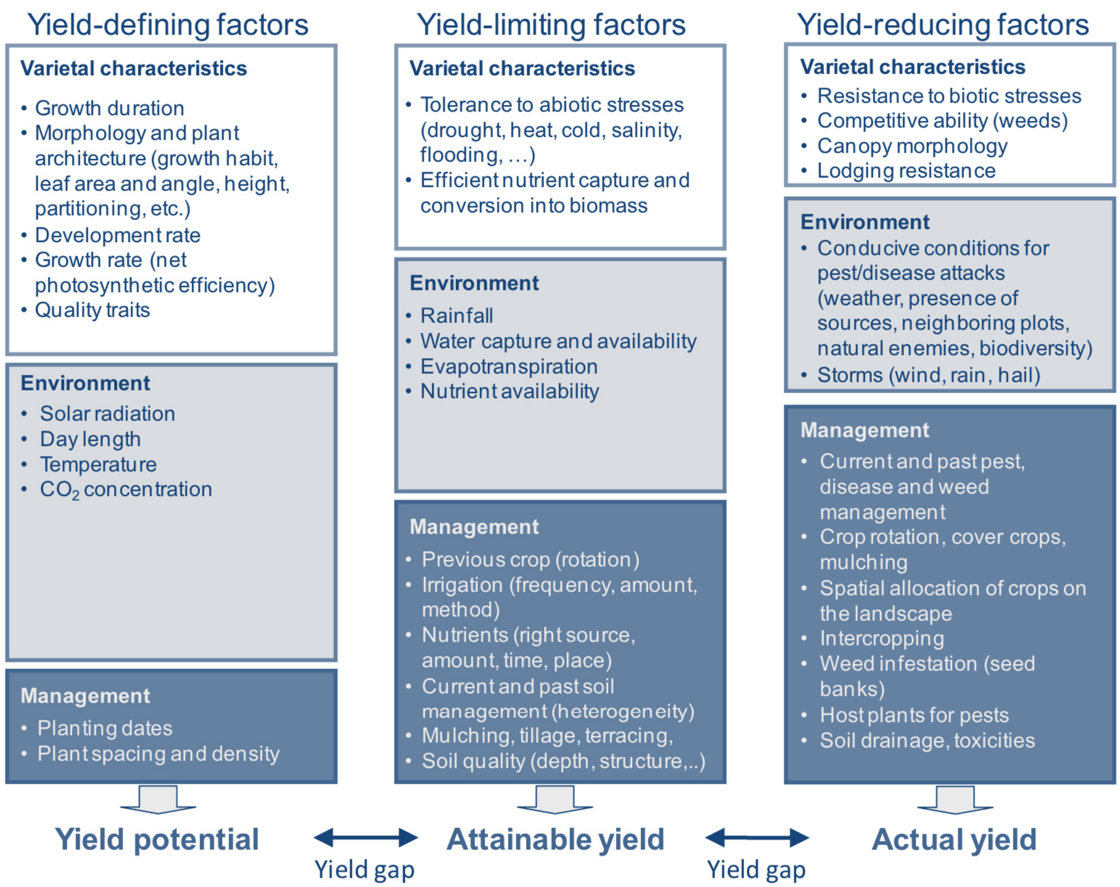

Figure 2-3. Yield-defining, yield-limiting and yield-reducing factors determine the exploitable yield gaps in crop production. Source: Modified from Tittonell and Giller[96].

Some yield gaps in food-deficient regions of the world can still be exploited through relatively simple interventions such as better seed, appropriate and efficient use of fertilizers, and better crop, soil and water management[92]. Likewise, low livestock productivity can be tackled through better feeding practices (quantity and quality of feed), improved animal health (preventative measures such as vaccines), better animal handling and transport, and robust breeding strategies. However, for most of the world it is generally necessary to move towards more precise, knowledge-intensive forms of

[n] Many different definitions of "yield gap" are in use and methods for quantifying them vary widely[24,91]. We use a biophysical definition of crop yield gaps following a production ecology concept that focuses on yields per unit land area (productive capacity and impact on the environment), recognizing that productivity per person is just as critical (in defining real food prices, real incomes across an economy, economic diversification, etc.).

agriculture – and provide the technologies and incentives that make it viable for farmers to adapt and adopt them. In crop production a key goal is to apply modern production ecology principles to improving the management of each and every field, no matter how small or how large it is[97]. Farmers and agricultural professionals must learn how varietal characteristics, the environment, and agronomic management determine what yield (and income) can be achieved at a given location (Fig. 2-3)[95,96,98]. The interplay of these factors determines both the productivity and overall efficiency of the system as well as its environmental impact.

Yield potential is defined as the maximum yield of a crop variety when grown in environments to which it is well adapted, with nutrients and water non-limiting, and pests and diseases effectively controlled. It is primarily defined by varietal characteristics and climate, mainly solar radiation and temperature regime[98]. For crops grown under rainfed conditions the amount of water available during the growing season determines the yield ceiling, i.e., the water-limited yield potential. Yield potential is highly variable across and within regions. It is impossible for a large population of farmers to have the perfection in crop and soil management required to achieve the full yield potential, and it would also not be cost-effective to aim for this because yield response to inputs follows diminishing returns as average farm yields approach the yield potential. Average farm yields often begin to plateau when they reach about 75 to 85% of the yield ceiling[9,24]. Hence, a realistic goal of SAI should be to move as many farmers as possible from current average yields to about 80% of the yield potential (or water-limited yield potential), which has been shown to be a general, profitable target for the yield that can be attained with good management[95]. This requires choosing the right variety and systematically improving soil, water, and crop, pest and disease management to adapt to the environment and close the yield gaps caused by yield-limiting as well as yield-reducing factors (Fig. 2-3).

Varieties with high yield potential, enhanced tolerance to abiotic and biotic stresses, and high nutrition and product value are a prerequisite for successful agriculture. The addition of high nutritional value would contribute significantly to food and nutritional security. Recent advances in gene discovery, biotechnology and genomics-based precision breeding methods have opened up new opportunities for genetic improvement that must be fully exploited[99,100,108,109], particularly those that can benefit smallholder farmers most. The full potential of modern biotechnology[o] for genetic improvement of plants and animals has to be harnessed faster because it is one of the key technologies that will be required for meeting multiple goals of SAI, including increasing productivity and protecting the environment (Box 2-1). Developing countries need a rationale debate about GM crops that thoroughly weighs the benefits and risks and leads to each country making informed decisions that are not swayed by politicized arguments dominant in Europe[110]. We must also recognize, however, that improvement of complex traits such as yield potential or drought tolerance remains much more challenging and slow, requiring long-term investment and a multitude of approaches[26,111-113].

Implementing SAI in crop production implies taking full advantage of genetic potential by implementing good agronomic principles tailored to the local context, including:

- Profitable and sustainable crop rotations and other forms of using functional diversity in time and space, including intercropping where appropriate
- Tillage, cover crop and crop residue management that conserves and improves soil productivity

[o] **Biotechnology** in agriculture includes a range of technologies used in crop and animal breeding programs. It includes conventional methods (e.g., molecular-marker assisted selection, tissue culture) as well as genetic engineering. The latter is often referred to as "genetic modification" (GM), "GMO", "GM food", or "transgenics". Genetic engineering involves a precise, mediated transfer of one or few genes (DNA sequences) from other organisms, but it may also involve mutation or deletion of genes.

- Access to quality seed of well-adapted varieties that meet local preferences or market demands
- Planting at the right time to maximize the attainable yield
- Maximizing the capture and efficient utilization of available water for high water productivity
- Precise, integrated use of mineral fertilizers and available organic nutrient sources to meet crop nutrient requirements with high efficiency and sustained soil quality
- Integrated pest management strategies that include host-plant resistance, functional biodiversity, biological control and the judicious use of pesticides
- Harvesting at the right time
- Optimizing recycling and use of biomass and agricultural by-products, including better use of crop residues for livestock feeding or other purposes

With the right approach and support mechanisms, agronomic interventions can lead to fast, large and sustainable productivity and efficiency gains (Box 2-2).

Box 2-1. Biotechnology as a component of SAI

Biotechnologies such as tissue culture, genomics, marker-assisted selection and genetic engineering can contribute to successful implementation of SAI strategies in many agricultural systems worldwide, to the benefit of both farmers and consumers. The application of DNA-based technologies can improve the effectiveness of conventional crop and animal improvement programs, allowing natural genetic diversity to be better understood and utilized[99,100]. Transgenic or GM approaches may be useful when the variation available in the natural gene pool is not sufficient to overcome major constraints to crop and animal productivity, improve tolerance to stresses and increase nutrition quality. The available scientific evidence is clear: biotechnology solutions are not necessarily more risky than conventional plant and animal breeding technologies, and they can be deployed safely under regulations that detect and prevent hazards to human health and the environment. As a result, commercially released GM crops have sharply reduced farmers' use of herbicides, pesticides and fossil fuels, while consumers' use of ingredients derived from GM crops has been no riskier than consuming the same foods containing ingredients from crop plants modified by conventional plant improvement techniques[101-103]. In their more than 15 years of existence, GM crops have contributed positively to commercial and smallholder agriculture in all regions where they have been introduced, in terms of farmers' profits, health, and agronomic and environmental impacts[104-106]. As with any other new technologies, farmers as well as consumers should have the right to chose from a range of available options, for which the scientific community must provide evidence-based, unbiased information. Genetic engineering solutions in agriculture need to be monitored and managed well, as integral components of SAI strategies and with measures in place that allow the detection and prevention of any risks that may occur, including legal or financial risks for farmers. Most of the GM solutions that have been commercialized so far have focused on single or few traits, e.g., insect resistance (Bt) or herbicide resistance in crops such as cotton, maize, soybean and canola. For GM technologies to play a more significant role in ensuring food and nutrition security as well as protecting the environment, more complex genetic engineering challenges will have to be tackled, including drought tolerance, nitrogen use efficiency and yield potential. Intellectual property needs to be protected, but it must also be made widely available for wider utilization in breeding programs of public institutions as well as small seed companies. Breeding and biotechnology capacity in national programs has to be expanded greatly in most developing countries. Rethinking of institutional arrangements, biosafety laws and variety release systems is required, towards lower costs and faster approval of GM crops/animals and greater participation by small companies and the public sector - but without comprising safety or environmental risks[107].

One major lesson from successful interventions is that simplistic, universal prescriptions or recommendations will not work. The principles of SAI can be applied to any production system and its associated value chain, no matter whether it is conventional, organic or some other form of agriculture. It can be done in farm enterprises of different sizes and degrees of market integration and will particularly benefit resource-limited, small farm enterprises. Actual crop yield, water productivity and profitability are to a large extent determined by weather and the quality of soil, water, nutrient and crop management – the interactions between genotype, environment and management. Knowledgeable farmers with access to good quality land, inputs and new technologies will be more successful in exploiting the location-specific yield potential than farmers who do not have these assets.

Box 2-2. Success through better agronomy extension in irrigated rice systems of South America

In recent years irrigated lowland rice yields have risen rapidly in some countries of South America and elsewhere at an annual growth rate four to five times the global average. For example, on about 1 million hectares in southern Brazil average irrigated rice yields stagnated around 5-5.5 t/ha from 1982 to 2002, but increased to 7-7.5 t/ha in recent years. A similar phenomenon has occurred in Uruguay, where rice yields rose by 25%, from about 6.5 t/ha in 2000 to over 8 t/ha at present. The major factors contributing to this success were:

- Strong public research and extension systems, including qualified, motivated extension agronomists
- Science-based, production-scale agronomic management principles that can be tailored to farm-specific needs
- A participatory research and extension approach, including key stakeholders and farmer-to-farmer extension
- Functioning markets, supply chains and local agri-businesses with transparent business relationships
- Good governance and supporting policies that avoided distortions or disincentives

Extension programs also reward farmers for meeting best management standards and environmental stewardship requirements, which are also communicated to rice consumers through branding schemes. Water consumption, nitrogen consumption, energy consumption and methane emissions per unit food produced have all decreased. Agrochemical use was reduced and soil and water quality meet high standards.

Another lesson is that SAI should not aim to blindly copy natural ecosystems that have not been optimized for food, feed, fiber or bioenergy production[114]. Instead, SAI can derive options from natural systems, traditional systems, industrial systems and "alternative" systems; from experimentation and traditional knowledge; from scientific theory and empirical observation. These options need to be tailored to local conditions by well-integrated research and development systems. Although many principles for a systematic SAI approach are generic, the scope for increasing eco-efficiency in agriculture can vary widely (Box 2-3).

Similar SAI concepts can be applied to a wide range of agricultural systems. Livestock systems play a particularly significant role for food and nutrition security, rural livelihoods and the economies of developing countries. They provide nourishment for rural and urban households, income and employment for producers and others working in value chains, and a crucial asset and safety net for the poor[45,51]. Increasing the productivity, resource efficiency and sustainability of livestock systems includes following principles such as[45,46,116]:

- Adopting management practices that improve animal health and welfare
- Increasing animal productivity and efficiency through genetic improvements and better feeding, including adoption of age-specific, balanced feed rations
- Decreasing pollution by optimizing critical metabolic and nutrient cycles (e.g., nitrogen, phosphorus, methane gas emissions)
- Enhancing diversity within animal production systems to strengthen their resilience
- Improving rangeland productivity, diversity and grazing management
- Adapting management practices that preserve biological diversity in livestock agroecosystems
- Using manure within comprehensive nutrient management systems while recognizing and mitigating its associated health and contamination risks

Box 2-3. Pathways for improving eco-efficiency will differ among diverse cropping systems

Global food security requires producing the required food and fiber crops concomitant with ecologically efficient use of resources. This eco-efficiency concept was used to diagnose the state of agricultural production in China (irrigated wheat–maize double-cropping systems), Zimbabwe (rainfed maize systems), and Australia (rainfed wheat systems)[115]. More than 3,000 surveyed crop yields were compared against simulated grain yields at actual levels of nitrogen (N) input. Many Australian commercial wheat farmers are close to existing production frontiers and gain little additional return from increasing their N input. Significant losses of N from their systems are infrequent and at low intensities relative to their level of grain production. These Australian farmers operate close to eco-efficient frontiers with regard to N. Innovations in technologies and practices are essential to increasing their production without added economic or environmental risks. In contrast, many Chinese farmers can reduce N input without sacrificing production through more efficient use of their fertilizer input. There are real prospects for the double-cropping systems on the North China Plain to achieve both production increases and reduced environmental risks. Zimbabwean farmers, on the other hand, have the opportunity for significant production increases by both improving their technical efficiency and increasing nitrogen and other inputs. Doing so will require improved management expertise and greater access to institutional support for addressing the higher risks that can be associated.

Aquaculture - the farmed production of fish, shellfish, and aquatic plants such as algae - is currently among the fastest growing animal food production sectors in many developed and developing countries. It will soon supply more than half of the world's seafood for human consumption[49,117]. Continued growth in aquaculture production is likely to come from further intensification, which is often accompanied by a range of resource and environmental problems. Novel culture systems, alternative feeding strategies, and species choices are among the SAI strategies for such systems, but policies that provide incentives for innovation and environmental improvement are equally important[117].

Further important components are urban food production and delivery systems, which have two facets: (i) bringing food from peri-urban and rural areas to meet the needs of urban centers and their inherent systems, policies and regulations; (ii) opportunities for producing food in the urban environment. The potential for urban food production needs to be assessed realistically, but there may also be important avenues for improving it within a SAI context (Box 2-4).

In summary, a flexible approach for SAI must embrace modern science and technology and combine it with local knowledge, enabling governance and business support systems to develop and implement location-specific solutions. In the short term there is an opportunity to address local and regional markets through incremental improvements. With improved performance and the expansion of regional infrastructure and governance, global markets may be accessed, depending on the commodity grown and its competitiveness. Importantly, SAI requires better access to and utilization of knowledge and information by all actors along the value chain.

2.3. Climate-smart agricultural landscapes

Implementing SAI in practice is also situated within broader concepts of a more Climate-Smart Agriculture (CSA), uniting the agendas of the agriculture, development and climate change communities. Historically, farmers have adapted their farming systems and management practices to changing climate and variable weather. This process needs to accelerate in our generation. In that context, CSA is a continuous process of improving agriculture through innovations in policies, technologies, management, and financing that aim to:

- Sustainably increase agricultural productivity and incomes;
- Strengthen the adaptive capacity and resilience of people, food production systems and ecosystems in agricultural landscapes;

- Reduce and/or remove greenhouse gases emissions, where possible[119,120].

The concept and practical solutions for CSA are still debated because the relationship between these three dimensions is poorly understood[121]. It often involves trade-offs, driven by different incentives by different actors. Why, for example, should a poor farmers invest in agricultural practices that may reduce GHG emissions if there are few if any immediate benefits related to his income or food security? In practice, many improved agricultural practices can be considered climate-smart, but not all may have the desirable short- and long-term benefits. Just from a plant breeding perspective, there are often trade-offs between yield gain and yield stability, if not resilience. Is mitigation, e.g., in livestock systems, compatible with intensification? Hard choices may often have to be made on trade-offs between intensification, mitigation and adaptation. Climate-smart agriculture should therefore be developed further, as an implementation concept that also utilizes the SAI principles stated above to bring us closer to operating within foreseeable local and planetary limits for agricultural and food systems[121]. Scientifically sound indicators and metrics must be defined to guide this process.

Box 2-4. What is the potential for urban food production?

There are complex and often well-integrated systems and processes (often private sector driven) that bring food to urban areas and ensure it can be reached by the urban populations through a range of traders, retail markets, shops and supermarkets, or direct purchasing from producers or middlemen by consumers through electronic and other means for door-to-door delivery. The need for packaging and transportation increases the carbon footprint of agricultural products and there are potential losses from poor postharvest management of perishable products. Where in place, inflexible regulatory systems between retailers and consumers minimize risk to the consumer while creating a large amount of wastage. There has always been urban food production in cities e.g. market gardens for perishable, high-value products and also for recreational or home production in gardens or through city-allocated land allotments. Where property rights are not well established, including many cities in Africa and Asia, there has been an opportunistic incursion onto available land for production of crop and animal products, and along rivers and streams. Most urban food production focuses on high-value and perishable products such as vegetables and milk. There are also opportunities for vertical production, rooftop gardens and small-scale crop production in cities to fill some commercial and household niches. What proportion of the food for cities can be safely grown within city boundaries remains unknown and it is also uncertain how much of this is actually marketed. Land is expected to be in even shorter supply as urban infrastructure deepens. Urban crop and animal producers and consumers also need to be aware of the possibility of contamination with heavy metals, pathogenic microorganisms, pesticides, manure and other byproducts where waters contaminated with industrial effluent and/or sewage are used for irrigation. New strategies and technologies for increasing "vertical" food production in cities are being studied[118]. However, the costs of this are likely to be uncompetitive with traditional supplies from rural and peri-urban sources. Current rates of urbanization suggest, even in less developed areas, that the rural population will start to decline absolutely over the period to 2030. There is likely to be land consolidation and growing labor productivity in rural-based agriculture resulting in increased productivity and lowering costs; it is unlikely that capital-intensive urban production will have a comparative advantage over increased labor and land efficiency in rural areas, but it will continue to play a local but important role in the food system.

Beyond achieving such climate-smart objectives, agricultural systems must also provide and protect a wide range of ecosystem services. Many need to be operated on principles of integrated landscape management, while explicitly incorporating adaptation and mitigation into their management objectives[122]. Such landscape approaches seek to provide principles and tools for allocating and managing land to achieve social, economic, and environmental objectives in areas where agriculture, mining, and other land uses compete with environmental and biodiversity goals[123]. Potential exists in many agricultural areas to realize greater efficiencies and multiple benefits through managing larger landscapes and regions. Examples include large-scale irrigation and rainwater harvesting systems; grazing reserves in a small portion of the landscape that can be accessed by livestock keepers in times of drought; ecological engineering approaches for integrated pest and disease management; management of invasive alien crop or animal species (e.g., exotic weeds, crop an animal diseases, fish); or payment for environmental services schemes. Promising examples have already emerged in all world regions.

There are many uncertainties, competing demands and other factors that often require making compromises in land use and landscape management. Achieving multiple objectives is an ongoing process subject to negotiation, learning, adaptation, and improvement. Ten principles have recently been proposed to guide the process of decision-making in landscape contexts:

1. Continual learning and adaptive management,
2. Common concern entry point,
3. Multiple scales,
4. Multifunctionality,
5. Multiple stakeholders,
6. Negotiated and transparent change logic,
7. Clarification of rights and responsibilities,
8. Participatory and user-friendly monitoring,
9. Resilience and
10. Strengthened stakeholder capacity[123].

3. Agriculture in the post-2015 action agenda for sustainable development

3.1. General considerations

Directly and indirectly agriculture will contribute to achieving interrelated development outcomes such as poverty, food and nutritional security, economic and social development, gender equality, energy, water, climate, biodiversity, peace and security, and disaster prevention or mitigation. A framework is needed for understanding and realizing these contributions, with clear goals and targets, effective solutions for concrete action, and indicators that allow measuring progress. Building on the Rio+20 outcome, sustainable development is a holistic concept with four interconnected dimensions: *economic development* (including ending poverty), *social inclusion*, *environmental sustainability*, and *good governance*[124]. Measures taken to improve one dimension often improve others[125].

Sustainable Development Goals (SDGs) for the post-2015 era and the concrete Targets for these goals still need to be agreed on by the global community. They will guide the public's understanding of complex sustainable development challenges, inspire action, promote integrated thinking, and foster accountability. They will be complementary to the tools of international law by providing a shared normative framework that fosters collaboration across countries[125]. Each country needs to choose its own sustainable development paths, with specific, achievable targets at country or local level and taking into account their current positions along these paths. We use the following definitions[125,126]:

Goal Expresses an ambitious, specific commitment. Lays out a single challenge with great impact. Should be universal, comprehensive, operational, and easy to understand.

Target Specific, measurable, attainable, time-bound sub-component that contributes in a major way to achievement of the goal, i.e., an outcome variable that is easy to understand, representing one major direction of change. To qualify as a target, the problem must be preventable or a way out of it is found through interventions in agriculture and food systems. Targets should be specified at the global and national level, reflecting the level of ambition of each country and the speed at which a country pursues a goal.

Indicator A sound, measurable metric to assess whether the target is being met, including detecting trends and anomalies. Often multiple indicators are used for this purpose. Indicators should be meaningful, sensitive to the most critical aspects of a target, reliable and doable in terms of available data and measurement protocols, quickly available, and easy to understand by policy makers, investors and other stakeholders. They should also allow for disaggregation, i.e., targets to be measured in various dimensions, such as by geography, socioeconomic status, gender, age, and ethnicity, for example.

Goals and targets for agriculture and food systems need to encourage systematic solutions for making food production, processing, trade and distribution more sustainable, equitable and resilient, thus also contributing to nutrition and other outcomes[127]. They also need to address the trade-offs between consumption in wealthier countries and its potential consequences for other countries. Where trade-offs are required in cases of scarce resources, the needs of the poorest and most vulnerable people must be addressed first, many of whom live in rural areas and are engaged in agriculture. The new SDGs and targets also need to mobilize attention and action to reverse or mitigate threats to food production from ecosystem degradation affecting landscapes and whole communities, many of which cannot be overcome with improved seeds or farm-level nutrient and water management solutions. These offer great opportunities for collaborative action between agriculture, rural development, environment and education ministries and other stakeholders in the SDGs.

Most targets should be defined as practically achievable targets for which decision-makers can be held accountable. Recognizing the aspirations of the Zero Hunger Challenge[p] we aim to provide guidance on pragmatic targets, indicators and approaches that could ultimately lead towards meeting that challenge. We recognize that solving global problems involves many transnational issues, but we propose that goals and targets should place strong emphasis on the responsibilities of countries, including developed and developing countries.

First contours of possible post-2015 SDGs and their specific targets are emerging. The UN System Task Team on the Post-2015 UN Development Agenda provided first suggestions, including a discussion of statistics and indicators for the post-2015 development agenda[128,129]. In its report to the UN Secretary General the High-Level Panel of Eminent Persons on the Post-2015 Development Agenda proposed 12 possible SDGs with 54 targets[126]. Agriculture makes direct and indirect contributions to 9 of the 12 goals proposed, but particularly to Goal 1 (End Poverty), Goal 5 (Ensure Food Security and Good Nutrition) and Goal 9 (Manage Natural Resource Assets Sustainably). The Sustainable Development Solutions Network (SDSN) proposed 10 priority development challenges addressing the four dimensions of sustainable development. They are interconnected and form the basis for 10 possible SDGs with 30 targets designed to trigger practical solutions that countries can pursue with high priority (Annex 2)[125].

We restrict our discussion to the SDGs and targets proposed by the SDSN, primarily to stimulate further discussion. Because poverty and hunger must be eradicated in our generation a prominent stand-alone goal should address that urgent need (Goal 1). The global development agenda should also have a goal that explicitly focuses on improving agricultural systems and rural development in an integrated manner (Goal 6), to adequately address the need for transformative changes that are required to make agriculture more productive and more sustainable, as underscored by the interim report of the Open Working Group on the Sustainable Development Goals. Food and nutrition security targets are fully embedded in these two goals, recognizing that adequate and nutritious food is a universal human right and all the states in the world have the responsibility to respect, secure and implement this right. Future goals should pay extra attention to the availability and quality of food during the first 1000 days (from conception until the age of two), because malnutrition under the age of two is fatal for a person's development in the longer term. We must also recognize and capture the contributions of agriculture to goals on gender equality and social inclusion, health, climate change and energy, ecosystem services and natural resources, and good governance.

The new SDG framework could more explicitly address sustainable landscape management as a goal or targets and indicators that focus on livelihood provision, ecosystem services, products, and resource efficiency as key landscape dimensions[130]. Difficulties in terms of political and administrative planning, implementation and monitoring may be associated with a landscape-based framework, but we encourage further discussion of this. Likewise, a holistic global framework such as FAO's Sustainability Assessment of Food And Agriculture (SAFA) could be applied for the assessment of sustainability along food and agriculture value chains, to establish an international reference for assessing trade-offs and synergies between all dimensions of sustainability[131]. Elements of it could also be applied to the SDGs and their targets and indicators.

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[p] Aspirational goals stated for the **Zero Hunger Challenge** are: (1) 100% access to adequate food for all, throughout the year; (2) Zero stunted children less than 2 years of age; (3) All food systems are sustainable; (4) 100% increase in smallholder productivity and income and (5) Zero loss or waste of food. www.un.org/en/zerohunger

Unless otherwise noted, the targets stated are for **2030** (relative to the current situation, i.e., 2010-2015). Most targets need to be specified at country or sub-national level. We propose indicators that link to existing ones, such as the current MDGs (www.**un**.org/millenniumgoals) and those used by many United Nations agencies and other international and national organizations, including the World Bank (http://data.worldbank.org), but we also propose some new ones that may be needed for assessing progress in agriculture and its associated functions. Some indicators may also be improved towards measuring more deeply the inequality within a country, and many should be disaggregated by gender. Both existing and new indicators will require improved data collection and other monitoring mechanisms. Statistical agencies should promote the use of advanced data tools, including remote sensing, real-time monitoring with smartphones, crowd sourcing, GIS mapping and other techniques.

Due to the diversity and complexity of agriculture and food systems, setting concrete targets for the next 15-20 years is challenging. The concept of *planetary boundaries*[q] is used by the SDSN for guiding the transformative changes needed for sustainable development on a global scale[125,132,133]. Achieving future growth within these boundaries will require the adoption of sustainable technologies and behaviors that decouple economic growth from unsustainable patterns of production and consumption[125,133]. There is an ongoing debate on the relevance of planetary boundaries for agriculture and how they could be quantified. For example, the currently proposed planetary boundaries for nitrogen (N) and phosphorus (P) flows have been arbitrarily set, do not include social dimensions, and would likely lead to severe risks for ensuring global food security[41]. Moreover, adoption of new technologies in agriculture is a slow and uneven process, which also affects what realistic growth rates for improving productivity and resource use efficiencies could be. Recognizing that major transformations in food systems will take time and also involve many trade-offs, the targets and aspirational outcomes we propose for the post-2015 period should be viewed as a starting point. For example, the main rationale for proposing to increase the efficiency of resources such as water, nutrients and energy in agriculture and food systems by 30% in 2030 relative to current levels (see Target 6a) is that, on a global scale, improvements in the efficiency of these resources should at least exceed the annual rates of yield increase required during that period. Just achieving this would be a major, welcome departure from the trajectories of the past five decades. Transformative changes that could lead to even greater efficiency gains will likely take more time, including radical shifts in diets or major reductions of food loss or waste.

We suggest outcome-oriented measures of success for most indicators, i.e., numerical values (in square brackets) that countries could aspire to achieve, for setting their own vision of success. They can be viewed as minimum thresholds to aim for, but require further analysis and consensus. Such quantitative targets will differ among countries, depending on their starting points and the different transformational pathways to enter. Hence, timelines and additional indicators could be adapted to national circumstances, and countries may also use additional targets and indicators. Customization and disaggregation of targets and indicators form the basis for tailoring practical solutions for meeting the aggregated global SDGs (Chapter 4). Implementation pathways require country-specific analyses and involvement by many stakeholders to exploit all opportunities, and to improve metrics and data gathering processes and other tools that enhance decision making, education, communication and behavioral change (Chapter 5). Building more reliable data systems that provide timely, disaggregated indicators to measure progress in all countries, sub-populations, and at all levels (local, sub-national,

[q] Planetary boundaries define the safe operating space for humanity in the Earth system. climate change, biodiversity loss, biochemical cycles (nitrogen and phosphorus loading), global freshwater use, land use change, ocean acidification, stratospheric ozone, chemical pollution, and atmospheric aerosol loading[132].

national, regional, global) will be vital for success. It requires the use of innovative technologies as well as greater, sustained investments in monitoring world agriculture and food systems (see Chapter 3.2). The subsequent discussion focuses on contributions of sustainable agriculture and food systems to Goals 1, 5, 6, 8, 9, and 10 (Annex 2). Agriculture also contributes to other Goals, such as Goals 3 and 4.

3.2. Sustainable Development Goals, Targets and Indicators for agriculture and food systems

GOAL 1: END EXTREME POVERTY INCLUDING HUNGER

End extreme poverty in all its forms (MDGs 1-7), including hunger, child stunting, malnutrition, and food insecurity. Support highly vulnerable countries.

Target 1a. End absolute income poverty ($1.25 or less per day) and hunger, including achieving food security and appropriate nutrition, and ending child stunting.		
Possible Indicators	**Comments**	**Aspirational outcomes**
Proportion of population with income below [$1.25] a day (PPP) (%)	Current MDG 1 indicator 1.1, but using the current World Bank threshold for poverty, i.e., the percentage of population living on less than $1.25 a day (PPP at 2005 prices). The threshold to use may require further adjustment. Global poverty rates cannot be directly compared with national level poverty rates, which are derived using country specific poverty lines estimated in local currencies. Multiple poverty lines can be used for further disaggregation and analysis. iresearch.worldbank.org/PovcalNet	The number of people living on less than [$1.25] a day is effectively zero by 2030 in every country.
Proportion of population living below a country's poverty line (%)	Similar to the current MDG 1 indicator 1.3; countries often have their own thresholds for what constitutes acceptable poverty for their citizens, defined at a national or sub-national level. This indicator would allow countries to move the poverty line upwards over time[126]. This indicator could also be defined as income or consumption share held by the lowest [x]%.	The share of people living below their country's 2015 national poverty threshold is less than [x]%
Proportion of population below minimum level of dietary energy consumption (%)	Current MDG 1 indicator 1.9; but could be measured in various ways. Calorie availability can be measured at the country level based on national food balance sheets (FAO), or at household level from food expenditure or consumption surveys. FAO uses country-specific cut-offs for minimum energy requirements calculated by the WHO for different age and gender groups[6]. This indicator could also be defined as the share of people consuming less than 2100 calories per day (depending on the region) to measure the proportion and total number of the most food-insecure people[7].	The share of the population not able to meet minimum calorie requirements is effectively zero by 2030 in every country.
Share of calories from non-staple foods (%)	A simple dietary diversity indicator that is well correlated with stunting, wasting and low Body Mass Index. Can be calculated from FAO food balance sheets, with staple foods consisting of cereals and root crops, but preferably from more disaggregated data sources that also allow assessing distribution differences within a country or within households[134].	The share of calories from non-staple foods has increased by [20]% by 2030 (relative to a 2010 baseline). The share of animal-derived protein in the diet of women and young children has increased by [20]%

	Other indicators could be used too, for example an indicator reflecting the share of animal protein in the diets of pregnant women and young children, which is likely to be related to anemia, stunting and other consequences of malnutrition.	in countries with high prevalence of malnutrition and low-meat and dairy diets.
Prevalence of stunting in children under [5] years of age (%)	Defined as percentage of children under five years of age whose height-for-age is below minus two standard deviations from the median of the WHO Child Growth Standards. Child growth data are widely available; WHO has maintained the Global Database on Child Growth and Malnutrition since 1986[135]. Good trend data already exist, but more global training will be needed on how to properly measure height at young age. Some experts suggest to use a stunting indicator defined as up to age 2 as a measure more sensitive to conditions for the most recently born.	The global number of children under [five / two] who are stunted (as a result of malnutrition) has been reduced by [70]% in 2030 relative to the 2010 baseline. By 2050, no country has any child stunting beyond levels occurring in normal populations.[r]
Prevalence of anemia in non-pregnant women of reproductive age (%)	Proportion of non-pregnant women in reproductive age (15-49 yrs.) with hemoglobin concentration of <120 g/L at sea level. Anemia is diagnosed through finger-prick blood sample tests. The test could be easily integrated in regular health or prenatal visit to capture all women of reproductive age. Data on anemia prevalence collected in 1993-2005 are available for 73% of non-pregnant women of reproductive age, in 82 countries[135].	Anemia in non-pregnant women of reproductive age has been reduced by [50]% in 2025 (relative to a baseline set in the 1993 - 2005 period)[136].

Target 1a and its indicators recognize that agriculture-led growth is essential for ending poverty, food insecurity and malnutrition. Although it has also been proposed to have a separate Goal on food security and nutrition[126], the SDSN proposes to include hunger and malnutrition under extreme poverty (Goal 1) with the rationale that both are challenges that affect rural as well as urban areas; hunger is not only a function of food availability; stunting and malnutrition are key dimensions of extreme poverty; and a single poverty/hunger goal ensures full continuity with the current MDG 1[125]. Continuing on current growth trends, about 5% of people will be in extreme poverty by 2030. Hence, with slightly faster growth it should be possible to eradicate extreme poverty[126]. GDP growth from agriculture is at least twice as effective in reducing poverty as growth generated in the non-agricultural sectors[74]. Considering the huge importance of food prices (relative to income) for eradicating poverty, another indicator could be defined that would relate food prices to incomes of different income segments[15]. It could provide some improvement over the first two indicators as it would allow for the immediate short term effects of food price spikes on real incomes and food security.

Food and nutritional security in target 1a has four dimensions:

- **Supply**: availability of enough food from diverse sources to meet the consumption needs of a healthy and nutritious diets, by either feeding oneself directly from productive land or other natural resources, or well-functioning distribution, processing and market systems.

[r] The World Health Assembly has endorsed a target aiming for a 40% reduction of the global number of children under five who are stunted by 2025, which we extrapolate here to 70% by 2030 as an ambitious target. Actual targets will vary widely by country, depending on current prevalence of stunting. Complete elimination of stunting is not possible, i.e., even in a healthy population a small proportion of children will fall below the cut off.

- **Access**: all members of society must have economic and physical access to sufficient food for a healthy and nutritious diet, through their incomes or special programs.
- **Utilization**: people must be able to absorb the food's nutrients. This involves sufficient intake, diverse diets, good food preparation, intra-household distribution of food, access to clean water and sanitation, and freedom from diseases and toxins that affect food utilization.
- **Stability**: year round and year-to-year stability of the food supply, as well as access and utilization of safe and nutritious food provides the foundation of food and nutritional security[137].

A broader vision of modern agriculture recognizes that solutions for reducing poverty and increasing incomes also need to be nutrition- and equity-sensitive. Beyond food staples we must ensure a stable and affordable supply of diverse micronutrient dense foods, such as legumes, pulses, vegetables, fruits, dairy and livestock and aquatic resources, thereby contributing to a more balanced healthy diet. Through a variety of innovations such as agronomic biofortification by adding micronutrients to fertilizers, biofortification breeding, or the promotion of vegetable gardens agriculture can improve food quality and health. Agricultural productivity improvements also provide increased income and employment opportunities that improve access to more nutritious food. Multi-sector interventions including household food security and dietary diversity are most efficient in reducing child stunting[138].

We propose four indicators that address the major hunger and malnutrition problems that need to be overcome in our generation, recognizing that many of the commonly used indices and measurement systems for food and nutritional security have shortcomings[134,139]. A calorie availability/deprivation indicator of some kind is probably still needed to measure extreme forms of food insecurity (undernourishment), but also because traditionally used ones such as the FAO index have a long history and reference base at national level. However, the nutritional relevance of calorie availability indicators is not always clear. The currently used methods, based on national food balance sheets (FAO) or household consumption surveys, all face sizeable measurement errors and limitations in terms of cross-country comparability, upscaling, disaggregation, and sensitivity to supply shocks. Measurement of hunger could probably be best obtained by collecting anthropometric data on stunted children[139] or dietary diversity indicators that are powerful predictors of economic status and malnutrition (both stunting and wasting). Both should be part of designing new monitoring systems at different scales[134].

Nutritional interventions should focus on overcoming malnutrition in women of reproductive age (particularly before and during pregnancy), and in children in the first 2 years of life[57]. For Goals 1 and 5, we recommend adopting and extrapolating the six targets (and indicators) for maternal, infant and under the age of 5 nutrition that have recently been endorsed by the World Health Assembly. They can be translated into realistic national targets based on the country-specific context[140]:

- 40% reduction of the global number of children under five who are stunted by 2025
- 50% reduction of anemia in non-pregnant women of reproductive age by 2025
- 30% reduction of low birth weight by 2025
- No increase in the prevalence of overweight in children under five by 2025
- Increase the rate of exclusive breastfeeding without supplementary feedings in the first six months to reach at least 50% by 2025
- Reduce childhood wasting to less than 5% by 2025 and maintain it below that level

Child stunting is a robust, non-specific indicator of nutritional status and overall health, including quantity and quality of dietary intake (mother & child), pre- and post-natal exposure to infections, environmental challenges, and care giving. It is linked to other adverse outcomes such as child mortality, delayed development, and lower wages as an adult[135,139]. Anemia in women of reproductive age is another important nutrition-related indicator. Anemia is closely linked to maternal mortality and other health risks. It is a multi-factorial disorder caused mainly by iron deficiency and infections and, to a lesser extent, by deficiencies of vitamin A, vitamin B12, folate and riboflavin[135]. Novel metrics that measure nutritional diversity in cropping systems could also be considered for defining a nutrition indicator that could be of particular relevance for smallholder farming areas[141].

GOAL 5: ACHIEVE HEALTH AND WELLBEING AT ALL AGES

Achieve universal health coverage at every stage of life, with particular emphasis on primary health services, including reproductive health, to ensure that all people receive quality health services without suffering financial hardship. All countries promote policies to help individuals make healthy and sustainable decisions regarding diet, physical activity, and other individual or social dimensions of health.

Target 5c. Promote healthy diets and physical activity, discourage unhealthy behaviors, such as smoking and excessive alcohol intake, and track subjective wellbeing and social capital.*		
Possible Indicators	**Comments**	**Aspirational outcomes**
Share of calories from non-staple foods (%)	Similar to the indicator proposed for Target 1a, this simple dietary diversity indicator could be used to track progress towards healthier diets in general, including in developed countries. For that purpose, it should be monitored at household level and disaggregated by income, gender, age, etc.	The share of calories from non-staple foods has increased by [20]% by 2030 relative to a 2015 baseline.
Per capita meat consumption (kg per capita)	Diet indicator that could be applied to track progress towards consuming less energy-intensive food in countries where a reduction in meat consumption is a major goal. Given the different nutritional and environmental impacts of consuming white (chicken, fish) or red (beef, pork, etc.) meat, this indicator could also focus on red meat only. In a different context, it could also be applied as a nutrition-related indicator in countries with low animal protein consumption and malnutrition.	[0]% increase or [x]% decrease in per capita [red] meat consumption by 2025 relative to a 2015 baseline in countries with currently high per capita [red] meat consumption.
Fraction of calories from added saturated fats and sugars (%)	Saturated fats and sugars are found naturally in some foods, but are often added when foods are processed by food companies or when they are prepared. This diet indicator could be used to limit and even reduce the health burdens from added saturated fats and sugars in processed foods.	[0]% increase or [x]% decrease in the fraction of calories from added saturated fats and sugars by 2025 relative to a 2015 baseline.
Prevalence of overweight and obese children under the age of [5] years (% or annual rate of change)	Share of overweight (weight-for-height above two standard deviations from the median of the WHO Child Growth Standards) in children under age 5[135]. Alternatively, this indicator could also be defined as prevalence of overweight and obesity at all ages, or using the Body Mass Index (BMI) as a metric. Overweight is difficult to measure during early age, with less reliable reference data available. Hence, this indicator could also be measured for adolescent girls and women of child-bearing age, since that affects not only mothers but their children too.	[0]% increase in the prevalence of overweight in children under [five], girls and/or adolescent girls and women of child-bearing age by 2025.

Prevalence of food contamination in the food system [to be defined]	An indicator could be defined to track food contamination caused by mycotoxins , microbes or other food safety issues. This indicator would provide an incentive to put surveillance systems in place to monitor food safety and support farmers, traders and processors in reducing contaminants.	To be defined.

Indicators for target 5c could address various aspects of the grand-scale behavioral changes required to make a difference towards healthier, less energy-intensive food baskets, with particular emphasis on reducing meat and sugar consumption among affluent consumers. Education is needed to ensure that the growing population understands the components of a healthy, balanced diet. Recent examples focus on obesity and Type-II diabetes, including national social sensitization programs such as the USDA's dietary guidelines, the 5-a-day program in the UK (where consumption of at least five portions of fruit and vegetables is promoted) and public service programs from both the health/medical and agriculture sectors. The education sector must have a strong role in ensuring that children are involved, as evidence shows that good eating and healthy habits start early. In resource-limited contexts, women often lack the knowledge, time or capability to provide balanced and adequate nutrition to their children. Agricultural and household drudgery can demand so much of women's time that they are unable to devote adequate time to childcare. In these contexts, effective interventions must engage men as well as women and children to reduce drudgery in agriculture or re-balance workloads and diets.

Reducing excess per capita meat consumption - that of "red" meat (from livestock as compared with chicken and fish) in particular - should be a major goal in those countries where it is among the major causes of cardiovascular disease, diabetes, and overweight and obesity. In addition to health benefits, this would also reduce the pressure on grain production and many environmental issues, and thus allow meeting the targets of Goals 6, 8 and 9. Hence, a suitable indicator could be defined for this purpose, for countries to set ambitious targets depending on their current consumption levels. The prevalence of overweight in children under the age of five years has been steadily growing in the past 20 years, at an annual rate of 3 to 5%[57,135]. Preventive interventions should combine healthy dietary practices (e.g., breastfeeding and a diet rich in fruits, vegetables, nuts, dairy products and whole grains and low in sugar-sweetened beverages) and increased level of physical activity. Overweight and obesity affect all age groups, but an immediate objective could be to measure it in young children or adolescent girls and women of child-bearing age for early identification of children at risk of overweight, and undertaking early corrective actions. If a country achieves no worsening of maternal obesity (Target 5c) and improvement in maternal anemia (Target 1a), many other health and gender-related targets will be achieved. In most countries data on diet, for example, is almost nonexistent. Hence, each country should establish and maintain a national health and nutrition survey.

GOAL 6: IMPROVE AGRICULTURE SYSTEMS AND RAISE RURAL PROSPERITY

Improve farming practices, rural infrastructure, and access to resources for food production to increase the productivity of agriculture, livestock, and fisheries, raise smallholder incomes, reduce environmental impacts, create better jobs, promote rural prosperity, and ensure resilience to climate change.

Target 6a. Ensure sustainable food production systems with high yields and high efficiency of water, nutrients, and energy, supporting nutritious diets with low food losses and waste.

Possible Indicators	Comments	Aspirational outcomes
Cereal yield growth rate (% p.a.)	Annual yield growth rate of major cereals (maize, rice, wheat, others), expressed in % or kg/ha harvested land. These crops are fundamental for achieving food and nutritional security. This indicator is critical for assessing whether investments in productivity growth of major food crops have the desired results. It could be disaggregated by cereal crops and sub-national scales, to verify progress against specific targets by crops and regions.	Annual yield growth rate of major food crops approaches or exceeds [1.5]% by 2020.
Crop yield gap (actual yield as % of yield potential)	Actual yield expressed as % of (water-limited) yield potential is a benchmark for productivity that also shows the exploitable yield gap[95]. It can be disaggregated by crops of highest priority for a country and is suitable for spatial disaggregation, from local to global scales. This indicator requires improved data collection and monitoring systems.	The majority of farms achieve [80]% of the attainable water-limited yield potential by 2030.
Livestock and fish productivity growth [to be defined]	A suitable indicator should be defined that expresses progress being made towards more efficient and sustainable production of animal products. The broader Livestock Production Index used by the World Bank is insufficiently nuanced for this, because it includes meat and milk from all sources, but also other dairy products, eggs, honey, raw silk, wool, and hides/skins.	Livestock and aquaculture productivity in developing countries has doubled by 2030, especially in Sub-Saharan Africa.
Full-chain nitrogen [phosphorus] use efficiency (% or rate of progress relative to a defined gap to close)	Defined as the ratio of nutrients in final products (e.g., human food consumed) to new nutrient inputs into terrestrial, aquatic and atmospheric cycles (e.g., nitrogen from chemical synthesis or biological N fixation, minerals mined and applied as fertilizers, etc.)[41]. It takes into account livestock and other stages of the food chain, as well as recycling. This indicator could track improvements in nutrient efficiencies along the full chain in countries with low efficiency levels. Because of different contexts, specific targets would have to be country-specific, i.e., defined so as to reduce the gap between current and targeted full-chain nutrient use efficiency levels. This indicator could also be disaggregated further, for example for major food systems (chains). A backcasting approach should be applied to identify technology and policy options for achieving specific full-chain efficiency targets.	Full-chain efficiency of nitrogen and phosphorus has increased by [x]% relative to current levels in each country with sub-optimal efficiency (e.g., high nutrient consumption relative to actual yield). For countries with low full-chain efficiency an aspirational target could be to reach, by 2030, a 30% increase relative to current levels.

Crop nitrogen use efficiency (%)	Defined as the ratio of nitrogen in harvested crop products to the amount of nitrogen applied (per cropping season or year). It is directly related to the efficiency of fertilizer use on agricultural land, including new technologies and stewardship programs targeting farmers and advisors[41]. Interpretation and specific targets for crop nitrogen use efficiency are context-specific, primarily depending on yield, current nitrogen use, soil quality and other factors.	Crop nitrogen efficiency increased by [30]% relative to current levels in countries with low efficiency. Unsustainable soil nutrient depletion halted and reversed in countries with insufficient nutrient use, resulting in increased crop production and economic return.
Access to irrigation (%)	Share of farmers or crop area with access to irrigation. Irrigation is an essential component of achieving food and nutritional security and reducing vulnerability in crop production. Many countries, also in Sub-Saharan Africa, have substantial potential for expanding irrigated agriculture in a sustainable manner. Concerns about unsustainable water consumption and depletion of water resources need to be addressed through additional indicators.	The share of irrigated agricultural land has increased by [x]% in countries with unexploited water resources.
Crop water productivity (tons of harvested product per unit irrigation water)	The proposed indicator is directly related to freshwater use for irrigation. Another alternative is to define water productivity as the efficiency with which water is converted to harvested product, i.e., the ratio between yield and seasonal water supply, including rainfall and irrigation[95].	Water productivity of crop production has increased by [30]% in countries with high water use for irrigation.
Share of agricultural produce loss and food waste (% of food production)	Methods developed by FAO could be the basis for this indicator, but they need to be improved further and first be applied to create a baseline[83]. Staple crops that are often consolidated after harvest for processing will provide better data for assessment of losses to provide a baseline. Crops grown on a small scale and consumed at household level will be very difficult to quantify in this sense, but are often those most affected by crop losses.	Post-harvest losses and food waste have been reduced by [30]% in 2030 and by [50]% in 2050 relative to current levels.

Target 6b. Halt forest and wetland conversion to agriculture, protect soil and land resources, and ensure that farming systems are resilient to climate change and disasters.		
Possible Indicators	**Comments**	**Aspirational outcomes**
Annual change in forest area (% p.a.)	Similar to the current MDG 7 indicator 7.1, but proposed to focus on the rate of change at national, sub-national and local levels to guide policy making and monitor implementation, including the use of high-resolution remote sensing. This indicator could also be expressed in absolute terms (square kilometers of forest area). Forest area is land under natural or planted stands of trees, excluding tree stands in agricultural production systems (e.g., plantations, agroforestry systems) and trees in urban parks and gardens. The indicator could be expanded to also include wetlands or other critical ecosystems.	[0]% annual forest conversion to crop or livestock agriculture by 2030. All countries have policies and enforcement systems in place to protect their most critical natural ecosystems.

Rate of change in arable land area (% p.a.)	Defined by FAO as land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow. This indicator could track expansion of agriculture into natural ecosystems as well as the loss of productive agricultural land to housing, industry, roads and other uses, which may threaten a country's food security.	[0]% annual change in [fertile] arable land area by 2030.
Land area without major constraints to agriculture (% or ha, or net rate of change)	Agricultural land not affected by [x] major soil fertility constraints or land degradation, based on established soil and land assessment methods and utilizing new digital mapping and monitoring efforts[142,143]. Based on a globally harmonized methodology, countries could define their own minimum list of specific land constraints that need to be tracked with regard to achieving land degradation neutrality or even improvement of land quality. The latter is important for countries that need to overcome major soil or land quality constraints, for example in Sub-Saharan Africa.	[0]% net land degradation by 2030, i.e., achieve a land degradation neutral world.
Proportion of farmers (or rural communities) covered by flood, drought and heat protection systems (%)	An indicator could be defined to quantify the proportion of farmers that have access to/have adopted new stress tolerant varieties and other resilience-enhancing technologies and/or are covered by policies, alert systems, crop insurance and other preparedness measures in areas that are most at risk to suffer from extreme climatic events .	At least [30]% of farmers have adopted soil and water-conserving production practices and all farmers have access to stress-tolerant, adapted varieties. All countries have policies, alert systems, insurance solutions, social safety nets, and other preparedness measures in place by 2030 to support farmers in years when crops or animals suffer.

<u>Target 6c.</u> Ensure universal access in rural areas to basic resources and infrastructure services (land, water, sanitation, modern energy, transport, mobile and broadband communication, agricultural inputs, and advisory services).		
Possible Indicators	**Comments**	**Aspirational outcomes**
Proportion of smallholder farmers with secure rights to land (%)	Secure land tenure is a key determinant for implementing sustainable agricultural intensification measures. This indicator could express land tenure status as the percentage of farmers (households) who have secure, permanent ownership or affordable long-term lease of the land they farm, disaggregated by region, income and gender. Women in particular need to be given better access to land, which should also be tracked with this indicator.	At least [80]% of all farmers have secure ownership or affordable long-term leases of the land they farm.

Access to improved water source in rural areas (%)	Similar to current MDG7 indicator 7.8, but following the World Bank definition. Percentage of the population with reasonable access to an adequate amount of water from an improved source, such as a household connection, public standpipe, borehole, protected well or spring, and rainwater collection. Reasonable access is defined as the availability of at least 20 liters a person a day from a source within one kilometer of the dwelling.	At least [80]% of all households in rural areas have access to good quality water sources.
Access to improved sanitation (%)	Percentage of households with access to effective sanitation. Sanitation is a critical part of public health and impacts agriculture; poor sanitation reduces household health due to infection and poor sanitation can affect the water source for communities as well as for agricultural production and postharvest value addition, thus compromising the health of consumers.	At least [80]% of all households in rural areas have access to improved sanitation.
Rural electrification rate (%)	Percentage of rural households with access to electricity, either through traditional grids, micro-grids (village level), or household supply (ex. rooftop solar). Data should be disaggregated as to whether the source is renewable or not to track progress on targets for renewable energy. Electricity is critical for cost-efficient agriculture as well as effective processing and storage of agricultural produce.	At least [80]% of all households in rural areas have access to affordable electricity.
Access to paved roads (% access within [x] km distance to road)	Access to paved roads is critical for many rural development processes, including access to inputs, markets, education, and health services. This indicator could be defined as percentage of rural households who are within [x] km of good quality paved roads (and/or rail) that provide connectivity to markets.	At least [80]% of all households in rural areas have access to good quality roads connecting them with local markets.
Access to drying, storage and processing facilities [to be defined]	Good infrastructure for drying and storing agricultural produce is critical for high quality and value as well as for reducing losses and contamination by mycotoxins or other food contaminants. Rural processing capacity would provide employment opportunities, enhance access to markets, and facilitate value addition (including the production of foods to enhance infant/child nutrition and reduce maternal drudgery).	At least [80]% of all households in rural areas have access to affordable local drying, storage and processing facilities.
Broadband mobile phone subscribers in rural areas (%)	Combines MDG8 indicators 8.15 and 8.16; total number or percentage of rural households (or people) who have pre- or post-paid cellular phone subscriptions with broadband connectivity. The indicator emphasizes broadband access as a key means for internet connectivity and thus access to more information and services.	At least [80]% of all households in rural areas have broadband internet connectivity.
Proportion of rural households with access to low-interest credit (%)	Access to affordable credit at the right time is critical for farmers to buy the inputs and services needed. It is also critical for many small and medium-size rural enterprises, including many run by women. This indicator could be defined as percentage of rural households who have access to sufficient financing at interest rates below [x]%. Alternatively, it could also be defined as the average rural lending rate.	At least [80]% of all households in rural areas have access to low-interest financing for critical agricultural capital, inputs and services.

Doing business in agriculture index or indicators	Further refining the "Doing Business" indicator used by the World Bank, an index or indicators could track different areas of the investment climate for small and medium agribusinesses, i.e., areas where policy reforms are most needed to stimulate business growth (inputs, farm services , land, water, finance, insurance, transport and markets, etc.).	To be identified. Discussions on developing new indicators are currently underway in the "Benchmarking the business of agriculture" initiative, in response to a G8 call.
Agricultural extension professionals per 1000 farmers	Without a functioning public/private extension system it is not possible to succeed with SAI. An indicator should be defined that tracks the total number of qualified agricultural professionals across different sectors that provide training, information and other extension support and services to farmers and small to medium enterprises in rural value chains. This indicator should include professionals with a minimum level of education/training/certification working in the public, private and civil society sectors.	All farmers have access to quality agricultural advisory services that provide locally relevant knowledge, information and other services.
Employment rate of rural youth and women (%)	Related to Target 3c. Percentage of young people (age 15-24) and women employed in rural areas, disaggregated by region and income. A youth and women employment indicator would track progress being made in creating new, better jobs in rural areas.	[50]% increase in rural youth and women employment through the creation of new and better jobs in agricultural value chains and service sectors in rural areas.

The indicators and aspirational outcomes proposed for Targets 6a-c reflect multiple dimensions involved in implementing SAI, including genetic, agro-ecological and socioeconomic innovations and the necessary enabling systems (Fig. 2-1). Growth in agricultural production can come from area expansion or intensification (increasing yield or cropping intensity per unit of agricultural land). Reliance on area expansion in Latin America and Sub-Saharan Africa must be limited, whereas in many parts of Asia, North America and Europe critical resources such as water and mineral fertilizers need to be managed more efficiently. Future growth in crop production will have to come from existing land whenever possible, by increasing yields and reducing losses and waste. This will be a primary requisite for reducing the expansion of agriculture into natural ecosystems and thus for achieving Target 6b. However, increasing productivity through SAI by itself may often not be sufficient to spare natural ecosystems from destruction[144]. Increasing profits may result in an incentive for conversion of natural ecosystems to agriculture, e.g., forests. Hence, other instruments to use include comprehensive conservation policies, land-use planning and adequate governance, including carefully crafted and enforced protection of critical natural ecosystems.

Simultaneously we will have to address unsustainable extraction of freshwater resources, increase nutrient efficiency and adapt to climate change[9]. Similarly, increases in production of animal source foods need to come primarily from increased productivity per animal rather than increased animal numbers. Any slowdown in productivity growth would mean that more land, water, energy, fertilizer, pesticides, labor and other inputs would be needed to meet the rising food demand, thus also raising the cost of food[3,5]. The plateauing of cereal yields in intensive production systems needs to be overcome, yield gaps will have to be closed in both the crop and livestock components of smallholder agricultural systems of the developing world, and incentives need to be provided for protecting soil resources. All this requires sensitive, measurable indicators that can track progress in these areas.

Other interesting options for indicators for target 6a should be explored. Since many biofuel crops directly compete with food production and also have other sustainability issues[145], an indicator could be defined that reflects the need to restrain the use of land for biofuels relative to food production. Moreover, an indicator such as the annual growth in Total Factor Productivity (TFP) could capture productivity growth as a whole, and has been used more widely in recent years[5]. Other indicators could measure the productivity of agricultural labor or land relative to the agricultural value produced and cereal prices[15]. They could also be disaggregated by sub-sector (crops and livestock). The use of value addition (in cereal equivalents) rather than gross production in all these measures allows for technical and economic efficiency, for the effects of large changes in real staple food prices, and for value differences across different agricultural products. The availability of reliable data at sub-national to district level will largely determine which indicators can be used.

In conjunction with the targets for Goal 9, target 6b focuses on critical natural resources for agriculture or affected by agriculture, including soil and land resources that form the basis for food security. The demand for fertile soil is increasing as the world population grows and is moving up the food chain. The mostly policy driven bioenergy sector has further increased the demand for agricultural land. On-site effects of soil degradation contribute to food insecurity and limit rural development. Off-site effects of soil degradation such as sedimentation of reservoirs and streambeds, eutrophication of waterbodies caused by erosion and CO_2 emissions caused by soil organic matter loss do not stop at national borders. Avoiding soil degradation and restoring degraded soils need to be addressed at a global as well as national level. The Rio+20 outcome document proposed to aim for a land degradation neutral world in which any land degradation has to be minimized and any unavoidable land degradations needs to be offset by regeneration (a natural process without human effort) and restoration (an active process induced by human effort). The third indicator proposed for target 6b tries to capture this, but others could be defined, including a more specific one that focuses on soil fertility constraints, for example[147].

The sustainable development path requires a *re-thinking of rural development and smallholder agriculture* towards structural transformations that include and benefit the poor – through new farming systems, technologies and business models that allow overcoming land constraints and enable greater market participation, thus creating new job opportunities[75,148-150]. We propose several indicators for target 6c that could address this. A land tenure indicator would track ownership/secure lease of land, which is one of the major constraints faced by farmers in developing countries. Insecurity about land prevents many from investing in productivity-enhancing measures. It is a prerequisite for implementing SAI and making use of modern technologies. Without secure tenure to land, hundreds of millions of smallholders will not be able to access credit or make major investments in soil improvement, machinery or other critical technologies. The *Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security*, which were developed through widespread global consultations and adopted by the Committee on World Food Security in 2012, provide helpful guidance on securing land tenure[151].

Sustainable agricultural intensification along whole value chains is an engine of socially inclusive growth in rural areas, giving a boost to smallholder farmers and new rural businesses along the value chain. The agriculture and food sector plays a key role in rural job creation, particularly for women and youth. Interventions aimed at improving access to markets, improved technologies and productive assets are key to enhancing smallholder participation in value chains and thus escaping poverty traps and subsistence farming[149]. Equitable, sustainable development requires recognizing the potential of rural areas by making villages and towns places that offer well-paid work and support proper education,

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[s] Soil degradation is not fully avoidable. Soil erosion rates on arable land for example are typically one or two orders of magnitude higher that soil reproduction rates.[146]

health and cultural infrastructure. To allow farmers and small rural enterprises to participate in the market, governments have to direct greater investments to rural transport, energy provision, irrigation, water supply, sanitation services, communication, prompt dissemination of information and improved crop storage infrastructure. Professional agricultural advisory services will play a major role in implementing SAI. New models must be found to speed up the delivery of new technologies through public and private sector channels. In addition to professional advisory services, farmers need their own innovation and knowledge-sharing networks which can link strategically to such services.

GOAL 8: CURB HUMAN-INDUCED CLIMATE CHANGE AND ENSURE SUSTAINABLE ENERGY

Curb greenhouse gas emissions from energy, industry, agriculture, the built environment, and land-use change to ensure a peak of global CO_2 emissions by 2020 and to head off the rapidly growing dangers of climate change. Promote sustainable energy for all.

Target 8b. **Reduce non-energy-related emissions of greenhouse gases through improved practices in agriculture, forestry, waste management, and industry.**		
Possible Indicators	**Comments**	**Aspirational outcomes**
Greenhouse gas emissions from agriculture (tons CO_2-equivalent per unit food-equivalent produced)	Greenhouse gas (GHG) emissions from agriculture, including direct and indirect emissions from crop and livestock production, forestry and associated land use changes; based on a new FAO database providing a complete and coherent time series of emission statistics over a reference period 1961–2010 at country level, using FAOSTAT (http://faostat.fao.org) activity data and IPCC methodology [152]. The IPCC Tier 1 approach has high uncertainty because it is heavily based on global default emission factors. Hence, this indicator should be improved by utilizing country-specific emission factors that are increasingly becoming available (Tier 2 approach).	GHG emissions from agriculture reduced by [30]% relative to current levels (per unit food-equivalent).
Adoption of GHG-saving management practices in agriculture (% area under GHG-saving management practices or tons of CO_2-equivalent)	In agriculture, a range of management practices can make substantial contributions to reducing GHG emissions, e.g., adoption of management practices to increase soil carbon sequestration, nutrient stewardship programs that reduce nitrous oxide emissions, or management practices that reduce methane emissions from rice or livestock. Depending on data availability and reliability, an indicator could be defined to track the adoption of such measures or their total impact on GHG-savings at different scales.	Adoption of GHG-saving management practices has increased to [x]% of the agricultural area.

Food systems as a whole contribute about 20–30% of global anthropogenic greenhouse gas (GHG) emissions, releasing 10-17 Gt CO_2 equivalent in 2008[31]. Agricultural production, including indirect emissions associated with land-cover change, contributes 80% to 86% of total food system emissions, with significant regional variation[31]. There are many opportunities for reducing GHG emissions on both the demand and the supply sides of the global food system[153,154], including some “triple win” solutions that could contribute to mitigation, adaptation, and improved food security[120]. Investment in yield improvements is among the most important mitigation strategies. It has been estimated that that each dollar invested in agricultural yields has resulted in 249 fewer kg CO_2-equivalent emissions relative to 1961 technology, avoiding 13.1 Gt CO_2-equivalent per year[155]. Hence, an indicator for target 8b should be a “yield adjusted” indicator, expressing GHG emissions per ton of product produced, which is more consistent with SAI principles than an indicator tracking gross GHG emission from agriculture. This would also allow taking differences among countries into account. A populous country in Sub-Saharan Africa in which population will double by 2050 can probably not be expected to reduce gross greenhouse gas emissions from agriculture compared to present. Data availability and reliability will by and large drive what indicators to use.

Other indicators for Target 8b could be defined to more specifically track the adoption of climate-smart agriculture technologies contributing to mitigation of GHG, for example carbon sequestration in agricultural soils and trees[156], nutrient management stewardship programs that contribute to reducing nitrous oxide emissions, or water-saving irrigation to reduce methane emissions from rice[157], provided that reliable and affordable mechanisms for scientific verification, implementation and monitoring can be established. Effective policy and business mechanisms need to be created to allow participation of farmers in recognized global, regional and national GHG reduction schemes, thus providing additional incentives for adopting resource-conserving production practices that can reduce GHG emissions, but also increase productivity, input efficiency and/or lower production costs.

GOAL 9: SECURE ECOSYSTEM SERVICES AND BIODIVERSITY, AND ENSURE GOOD MANAGEMENT OF WATER AND OTHER NATURAL RESOURCES

Biodiversity, marine, and terrestrial ecosystems of local, regional, and global significance are inventoried, managed, and monitored to ensure the continuation of resilient and adaptive life support systems and to support sustainable development. Water and other natural resources are managed sustainably and transparently to support inclusive economic and human development.

Target 9a. **Ensure resilient and productive ecosystems by adopting policies and legislation that address drivers of ecosystem degradation, and requiring individuals, businesses and governments to pay the social cost of pollution and use of environmental services.**		
Possible Indicators	**Comments**	**Aspirational outcomes**
Genetic diversity of terrestrial domesticated animals	In the absence of direct measures at genetic level, the status of domestic breed populations provides the best available indication of trends in diversity. This indicator is based on the Domestic Animal Diversity Information System of FAO (DAD-IS, dad.fao.org). DAD-IS covers more than 30 species used for food and agriculture and includes data on the size and structure of breed populations. www.bipindicators.net/domesticatedanimals	The adopting of cross breeds with improved genetics has increased by [x]% and the genetic diversity of domesticated animals farmed has increased by [x]% relative to current levels.
Genetic diversity of cultivated plant species [to be defined]	A suitable indicator could be defined to track the status of conservation of critical crop genetic resources and its utilization in crop improvement programs.	The genetic diversity of cultivated crops farmed has been effectively conserved and is widely utilized in crop improvement programs.
Loss of reactive nitrogen [phosphorus] to the environment (kg/ha)	This indicator could complement the nutrient efficiency indictors proposed for Target 6a by focusing more explicitly on direct losses of biologically and chemically reactive nutrient forms that are caused by various mechanisms from fertilizer, human and animal waste, industry, or organic amendments. They often result in transport of such compounds by air or water to distant areas. In nutrient-limited ecosystems this leads to eutrophication of freshwater streams, lakes	Deposition of non-indigenous nutrients on natural ecosystems (terrestrial and aquatic) has been reduced by at least [30]% relative to current levels, with several countries going further to reach levels that are not detrimental to ecosystem

	and coastal ecosystems, acidification of forests and soils, and loss of biodiversity. This indicator is more difficult to measure and mainly of interest to selected countries in which high nutrient loads cause damage to ecosystem functions. www.bipindicators.net/nitrogenloss	function and biodiversity.

Target 9c. All governments and businesses commit to the sustainable, integrated, and transparent management of water, agricultural land, forests, fisheries, mining, and hydrocarbon resources to support inclusive economic development and the achievement of all SDGs.		
Possible Indicators	**Comments**	**Aspirational outcomes**
Extent of forest and forest types (%)	MDG7 indicator 7.1 and similar to the forest indicator under Target 6b, but focusing on less regular, larger scale assessment. The extent of forests is one of the key indicators developed to track progress towards MDG 7. Global assessments of the world's forests are currently carried out at 5 year intervals by FAO. www.bipindicators.net/forestextent This indicator could be expanded or supplemented with other indicators to also track the extent and quality other ecosystems, particularly wetlands.	By 2020, the rate of net loss of all natural habitats, including forests, is at least halved, and where feasible brought close to zero by 2030 (including land reclaimed or reconverted from agriculture to wetland or forest). Degradation and fragmentation is significantly reduced.
Coverage of protected areas (% or km^2)	Calculated using all designated protected areas recorded in the World Database on Protected Areas (WDPA) with a known size, including marine and terrestrial protected areas. Global, regional and national time series from 1872 onwards. www.bipindicators.net/pacoverage	At least [20]% of terrestrial and inland water, and [15]% of coastal and marine areas, especially areas of importance for biodiversity and ecosystem services, are protected.
Proportion of fish stock in safe biological limits (%)	A measure of the sustainability of fishery resources in the context of aquatic ecosystem sustainability. It reflects fishery production and its social-economic benefits, and can be used for the formulation of fishery policy and the development of fishery management plans. The FAO assessment classifies fish stocks into three categories: overexploited, fully exploited and under-exploited. www.bipindicators.net/fishstocksinsafebiologicallimits	All fish stocks are managed and legally harvested sustainably within their biological limits, applying ecosystem-based approaches, so that overfishing is avoided.
Annual water withdrawal by agriculture (million cubic meters)	An indicator for the overall trends in water consumption, measured at different scales (e.g., regional/basin, national, watershed, irrigation system). It could also be defined as agriculture's share of total water consumption or in relation to the amount of water that can be used sustainably in an area.	Water withdrawal for agriculture is within agreed limits to avoid unsustainable withdrawal of water resources.
Share of land, fisheries and forest area covered by responsible governance policies (%)	Based on voluntary guidelines for responsible governance of tenure of land, fisheries and forests, countries need to develop their own laws and policies[151]. An indicator should be defined that tracks progress in implementing such laws and guidelines.	Laws and policies for responsible governance of tenure of land, fisheries and forests are implemented on at least [90]% of a country's land area. Incentives harmful to biodiversity are eliminated.

Share of extractive industries' income spent on rural development and environmental protection (%)	An indicator should be defined that tracks a country's progress in utilizing income generated from extractive industries to support rural (infrastructure) development (Goal 6) and environmental protection (Goal 9), i.e., measures that particularly benefit the poor.	In low- or middle-income countries, at least [20]% of a country's income from extractive industries and other land development investments is utilized to support socially inclusive rural development and environmental protection measures.

In the medium to long term, farmers have no economic or other incentive to destroy the environment they operate in. They care about the quality of their land, the quality and safety of food they produce, and the environment. Notwithstanding this, agriculture can negatively impact the environment in many ways[132,158], and it plays a major role in ensuring that critical ecosystems on Earth are preserved, resilient and fully functional. Concepts, tools, and mechanisms for valuing ecosystem services need to be fully developed and they need to lead to action, including participation by millions of smallholder farmers and including benefits for them. Agricultural ecosystems must be managed as part of the wider landscape, reinforcing natural resilience. Successful strategies for biodiversity management and ecosystem preservation are complex to design and require coordinated policies over a long time frame. They need to be based on science, but generally include a combination of voluntary guidelines, enforced legal protection of critical natural ecosystems, social mobilization and changing business behavior.

The proposed SDG Targets 9a and 9c in conjunction with the other SDGs cover many of the 20 Aichi Biodiversity Targets (www.cbd.int/sp/targets), which were developed under the Convention for Biological Diversity as operational milestones to be achieved by 2020. We generally support these targets and extrapolate some of them to 2030. However, the diversity and specificity of ecosystems around the world makes it difficult to select just a few outcome targets and indicators that are applicable in every country. Countries need to achieve locally-defined targets to record and manage their key ecosystems by adopting policies and legislation that address drivers of degradation and biodiversity loss, and require individuals, businesses, and governments to pay the social cost of pollution and for the use of environmental services[125]. We only provide a few examples of possible indicators that could be used to track the impacts of agriculture on biodiversity and ecosystem services. Many more have been proposed by numerous organizations to monitor multiple dimensions of ecosystem health in agricultural landscapes, for example those proposed by the Biodiversity Indicators Partnership (www.bipindicators.net). Actual usage will primarily depend on data availability and reliability, which would require substantial investments in improving current monitoring systems, particularly in low-income and fragile countries.

Water use cuts across Goals 6 (Agriculture), 7 (Cities and Industry), and 9 (Ecosystems). Here we include a proposed indicator that focuses on tracking freshwater use by agriculture, as the largest water-consuming sector. By 2050 over 40% of the world's population may be living in river basins experiencing severe water stress[159]. Many countries face growing water stress and virtually all must improve the integrated and sustainable management of their water resources. This will require long-term strategies involving governments, communities, and businesses to balance sustainable supply and use, reduce water loss, improve water retention, and lower pollution. Regions, countries and local communities need to have a clear understanding of the peak limits to freshwater use, in order to develop sound policies and implementation guidelines for sustainable management and governance of water resources at different scales[160]. Following recently agreed voluntary guidelines for responsible governance of tenure of land, fisheries and forests[151], countries should craft their own policies to ensure equitable, inclusive access by the rural poor to these critical resources.

Growth corridors driven by extractive industries (mining, hydrocarbons) as well as other agribusiness-driven large-scale land development schemes are penetrating rapidly into areas where agriculture has been constrained by lack of resources and access to markets, particularly in Africa[161,162]. Although this could unleash major improvements in rural infrastructure and expansion of arable crops, governance weaknesses may also lead to environmental damage and further marginalization of poor smallholders. Transparent governance and management of these developments is urgently needed, including laws and policies that ensure sustainable practices and equitable revenue sharing to support environmental protection and rural development. Rural and agricultural development are also much influenced by industries drawing rural labor into factories and industrial zones, the export of human capital to other countries, and extractive industries (oil, gas, coal, minerals) as a mega sector of many economies. All of these can be a significant source of investment for speeding up structural transformation in rural areas. The post-2015 agenda will need to find creative institutional and policy instruments to harness this potential to advance food security and inclusive rural development, including suitable indicators that capture these processes and their environmental impact.

GOAL 10: TRANSFORM GOVERNANCE FOR SUSTAINABLE DEVELOPMENT

The public sector, business, and other stakeholders commit to good governance, including transparency, accountability, access to information, participation, an end to tax and secrecy havens, and efforts to stamp out corruption. The international rules governing international finance, trade, corporate reporting, technology, and intellectual property are made consistent with achieving the SDGs. The financing of poverty reduction and global public goods including efforts to head off climate change are strengthened and based on a graduated set of global rights and responsibilities.

Target 10b. Adequate domestic and international public finance for ending extreme poverty, providing global public goods, capacity building, and transferring technologies, including 0.7 percent of GNI in ODA for all high-income countries, and an additional $100 billion per year in official climate financing by 2020.

Possible Indicators	Comments	Aspirational outcomes
Share of government spending on agriculture (%)	This indicator measures the proportion of the national government budget spent on agriculture. It should also measure the actual release or utilization of funds. Because the share of agriculture in the overall economy declines as countries move up the ladder, the targets for this indicator may vary accordingly. African governments in CAADP have agreed to increase public investment in agriculture to a minimum of 10% of their national budgets. The indicator could be further disaggregated to track spending by sectors or specific target groups.	During the entire 2015-2030 period, all countries with an agriculture-based economy spend at least [10]% of their national budgets on supporting the agricultural sector in their country.
Agricultural R&D spending (% change p.a. or % of agricultural GDP)	A suitable indicator needs to be defined to express a country's agricultural R&D commitment, with specific targets to be set by each country. One possibility is to define it as growth rate in agricultural R&D spending. Another indicator is the agricultural research intensity ratio, which expresses agricultural research spending relative to agricultural gross domestic product (GDP) but requires context-specific target setting and interpretation[163]. Country data are available in the Agricultural Science and Technology (ASTI) database. www.asti.cgiar.org	During the entire 2015-2030 period, annual government spending on agricultural research and extension increases by at least [5]% per year in low- and medium-income countries; agricultural research intensity reaches at least [1]% of agricultural GDP.

Share of ODA spending on agriculture (%)	Proportion of bilateral ODA funds allocated to agriculture (including forestry and fisheries), including support for R&D, human resources development, and institutional capacity building. www.oecd.org/dac/stats	During the entire 2015-2030 period, all high-income countries meet the 0.7% of Gross National Income (GNI) target for ODA, spend at least [10]% of their ODA funding on agriculture, and spend an additional [x]% on rural development.

Increasing and sustaining investment in agriculture and food systems in a responsible manner is essential for sustainable development. Both domestic government spending and Official Development Assistance (ODA) play a key role in implementing the SAI agenda. Both require sustained commitments to meet the minimum investment levels required, and those making critical decisions need to be well informed and able to prioritize and target investments based on the best available evidence. Countries need to set their own ambitious targets for agricultural and rural development. A combination of public and private financing will be required to ensure full coverage of all investment needs in an equitable manner. Governments must lead by committing to strong and sustained support of the agricultural sector. Most low-income countries and agriculture-based or transition economies, particularly those in Sub-Saharan Africa, should aim to spend at least 10% of their national or state budgets on accelerating agricultural growth[t]. Transparent principles and mechanisms are needed to ensure that farmers, small producers and businesses – and women in particular - are at the center of the investment strategy and also benefit from investments in public goods such as infrastructure, price support for inputs and outputs, research and extension.

Investments in public agricultural research should receive high priority and be of a more long-term, strategic nature. To be effective, national research and extension systems need to establish minimum capacities across all relevant disciplines and major commodities. As 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, this can be a transformational change. Globally, annual growth in agricultural R&D spending averaged 2.4% for the period 2000-2008, but many low- to middle-income countries have already accelerated their agricultural R&D spending to annual rates of 5% or more in recent years[163]. We propose that this should be a minimum, sustained target for all developing countries, although some, starting from a lower base, may have to do even more. Most low- to middle-income countries should aim to spend at least 1% of their agricultural GDP on public agricultural R&D. New models for research and extension systems are need in many countries to also ensure better focus and more sustainable funding. Farmer-driven research and extension models would ensure greater focus on issues important to them.

Aid to agriculture from ODA programs by developed countries and multilateral agencies fell from about US$ 11-12 billon in the mid-1980s to a little over US$ 5 billion in the mid-2000s[u]. As a proportion of total ODA financing, the share of aid to agriculture declined from 17% to 6% during the same period, revealing a clear relative neglect of the sector[164]. Agricultural ODA funding has increased to over US$ 10.5 billion (current value) in recent years, but its share was still only 6.2% of total ODA in 2011 (www.oecd.org/dac/stats). ODA investments in agriculture need to accelerate to make up for nearly 20 years of neglect, and these higher investments need to continue over the long term. All donors need to commit to meeting minimum targets. In 2007-08, just three countries (the United States, Japan and

[t] We cite this as an aspirational target based on what has been proposed in CAADP, www.nepad-caadp.net.
[u] The OECD analysis includes 22 DAC countries and 8 multilateral agencies.

France) accounted for more than half of all bilateral aid commitments to agriculture, and only three countries (Finland, France and Switzerland) allocated 10% or more of their ODA funds to agriculture. We propose that all donor countries should meet the 10% agriculture ODA target, and that donors also should ensure that no country in need is neglected. Utilization of ODA on agriculture should be monitored in a transparent, more effective manner to ensure that it achieves the expected results. Target 10b should also be concerned with effective and efficient use of available domestic and international finance for agricultural development, for which an indicator could be defined.

Other indices can be used for scoring the broader performance of the agricultural sector and its changes over time. Discussions are currently ongoing to develop a new Agricultural Transformation Index (ATI), made up of sub-indices or component indicators which would provide actionable measures of country performance and also help measure aid effectiveness (www.agriculturaltransformationindex.org). Agribusiness and investment climate, inclusiveness of policies, productivity, sustainability, and markets could be among the performance areas to be included in such an index.

3.3. Improving metrics, data and access to information

Without clear metrics and a well-designed research and institutional approach to make the metrics operational, reaching the targets for sustainable development will remain an amorphous goal. Countries must have the capacities to measure robust indicators of progress. Metrics for agriculture and nutrition are needed that steer policy, production, and consumption decisions along a course that will lead to continuous improvements. Metrics are important for setting a baseline by which to measure progress; tracking and anticipating socioeconomic, nutritional, and ecological change; diagnosing constraints; constructively engaging public, private, and NGO participants; and identifying appropriate policy responses[143]. Indicators inform action, but many of the currently used metrics are inadequate or in conflict with each other, obscuring clear guidelines for policymakers and practitioners. Unfortunately, estimating even basic metrics on crop yields, prevalence rates and patterns of different aspects of food security, or environmental impact remains difficult[91,134,165]. The statistical capacities of Sub-Saharan African countries, for example, have fallen into disarray, resulting in numbers that substantially misstate the actual state of affairs[166]. Efforts to evaluate the cross-sectoral performance of agriculture are currently hugely hampered by insufficient data, inconsistent measurement protocols, uncertainties about the right scale of measurement, weaknesses in models, and lack of investment in monitoring systems that take full advantage of new technologies such as remote sensing.

Aggregate national data provided by international organizations such as FAO and The World Bank are often used to capture agricultural production and input use, changes in land use, food supplies available for consumption per capita, and average poverty rates that infer food access. These data typically fail to account for income distribution, agricultural waste, seasonal swings in food production and consumption, shocks associated with weather and war, and uncertainties related to market and climate dynamics. Local social characteristics, such as net producer vs. consumer status, education, and health, are absent in these aggregate metrics. Ecological change related to soils, water, and crop genetic diversity is not measured consistently across countries at scales that matter for private sector investment and policy response. Local measures of economic, social, and ecological change, when implemented, are often costly, discontinuous over time, and inconsistent from one location to another. Such measures can be useful for addressing specific problems at certain times and locations, but they require significant scaling to be beneficial for monitoring regional and global food systems.

Developing a core set of agreed-upon indicators and collecting the necessary data in a systematic and reliable manner is a matter of high priority and will require substantial investment in people and infrastructure, including new information technology. From a policy and decision-making standpoint, what sorts of information would be most useful for implementing a sustainable agricultural intensification in the future? In Chapter 3.2. we discussed - as examples - a set of indicators that could be used to monitor the major outcomes of sustainable agricultural intensification (food and nutritional security, economic and social development, and environmental sustainability) and some of the enabling components required. Many of them fulfill the main requirements (Box 3-1), but some will also require further analysis and improvement. Subsequently, we discuss some of the major data gaps and make suggestions for how to gradually overcome them.

Box 3-1: Key consideration for metrics used in monitoring agriculture

- Metrics must be well defined and meaningful (have a clear mechanistic meaning and relation to specific development goals/targets), measurable, motivational for positive change, and easy to understand and to communicate to those who need to be the agents of change in the future: farmers, policy makers, executives, consumers, youth, etc.
- Metrics should provide cross-sectional representation and thus include measurement of biophysical, economic, social, and nutritional change.
- Metrics must allow measuring trends over time against a well-established baseline and they should allow integrated assessment across different scales[134,143,165,167].
- A central objective of sustainable development is to ensure social inclusion. Metrics should go beyond reporting average national indicators. Where appropriate and feasible, metrics should be disaggregated according to gender, geography, socioeconomic status, disability, ethnicity, age, and other dimensions in order to track and address marginalization and inequalities across sub-populations.
- In practice, the choice among metrics involves trade-offs in terms of precision, scale, and cost[165]. It is thus important to clarify the goals of measurement from the outset.
- Irrespective of current constraints, an overall minimum set of "universal" indicators is needed. These should be consistent metrics that provide broad, general information that can be supplemented with others that are more tailored to regional or local applications or to specific questions[167].
- In order to avoid an oppressive list of indicators that might be inconsistent across time or space, it is also important to identify proxies that can cover several of these information criteria.
- Engaging the intended users in developing the right metrics and involving them in the data collection and interpretation of results is likely to increase the chance for success.
- An adaptive measurement strategy is needed to ensure that metrics and monitoring procedures evolve as the relevant questions for sustainable agricultural intensification change over time, particularly with regard to ecological and environmental questions[167,168]. Enabling conditions should be created for stakeholders to advance the metrics.
- Monitoring and modeling can play complementary roles.
- Indicators should be few, with well tested methodology, guidelines and tools to be shared with countries to allow them to develop their own metrics and collect data on their own. Efforts should be made to support countries in taking ownership of those few SDG indicators at the ministerial and institutional level, and assist them with adopting the best available data collection methods.
- Metrics should make use of already available international and national data. Significant investments should focus on improving local, national, and global data collection and processing, including using new tools (GIS, remote sensing, social networking, mobile phones, crowd sourcing, etc.) as well as existing ones. Where applicable, on-farm and within-village measurement capability should be created using information technology. As a result of the information revolution, the SDGs should be supported by online, real-time, place-based, and highly disaggregated data, resulting in public databases for monitoring and public participation.

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 conclusions[169]. 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. There is a need to create in each country a central register using baseline census data (population and agriculture) and update these records regularly with data from many other sources, including surveys, rapid monitoring, satellite images on crop/area cultivated, yield, etc. The national household survey mechanism should still be supported, but simplified and made easy for respondents so as to get more reliable information on issues not captured by census and administrative records. International organizations, such as the agencies, funds, and programs of the United Nations should support countries in improving the quality and timeliness of data collection. Where official development assistance is required to finance improved data systems, these investments should be supported so that progress in achieving the SDGs can be monitored in real time. We need to simplify the data collection methods using simple questionnaires at different time periods. With the right technology, age census data can be linked to a country's administrative records so that each individual record is automatically updated, thus avoiding time-consuming and expensive surveys.

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. Uncertainties also concern the relative roles of net producers and net consumers, such as where they are or how they respond to agricultural market fluctuations. Africa, India and China are of particular importance because they together account for more than half of the world's population and the majority of the world's food insecure. We cannot tell for sure whether the worlds' population will be 9 or 10 billion people by 2050, but it is critical to know where additional people will be and what they will eat. An additional 1 billion people has huge implications for additional food need, but it can also result in the loss of over 100 million hectares of agricultural land to 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 that underpin existing economic models are often sparse and inconsistent. It is difficult to assess, understand and project changes in consumer behavior because of large cultural and economic differences among and within countries. Such information needs to be collected more regularly, primarily at the household level and food chain scales.

On the food consumption side, what policymakers need are:

- Cross-sectional information that includes comparisons between different social groups, regions and net producers vs. net consumers
- Information on long-term trends, patterns of seasonality and impact of production shocks on food intake and incomes
- Data on nutritional intake that include macro- and micro nutrients over time (both seasonal and year-to-year) and space (within and between countries)

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 generally do not have spatial data on poverty gaps or hunger, and hunger data are not very reliable because they are often food balance sheet based[134]. They need to be disaggregated further, 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. The various agencies involved in the agriculture and health sectors should develop common and internationally comparable dietary quality indicators from household survey data (ideally with separate indicators for children, women and men). Just as important as collecting better data is the development of a new generation of food system models for policymakers that fully incorporate nutrition, environmental, and climate elements and their interactions.

On the supply side numerous uncertainties exist about the general quality of agricultural and other statistics in many countries, including data on crop and livestock production, fertilizer use, irrigation water, labor, agrochemicals and many others. The available information on fertilizer and pesticide use by crops, for example, is sparse in product detail and spatial resolution, not up to date, and generally not verified at farm-scale. 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 by national statistical agencies that in many countries lack human resources, technology and operational funds. 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. It needs to be substantially improved in terms of spatial resolution and coverage as well as quality of data. Real-time, high resolution satellite imagery, particularly radar that penetrates clouds, can be of tremendous value for improving basic crop statistics, for making crop forecasts, and for assessing crop damage. The technology has already been demonstrated for contrasting regions, including commercial-scale corn farming in the USA[170], assessing temporal changes in rice cropping in Nepal[171], and real-time monitoring of smallholder agriculture in Malawi[172]. It needs to become available to everyone, adapted for all of the world's major agricultural systems, and effectively utilized by national statistical agencies. Similar efforts are needed to improve many others agricultural statistics, including for the livestock and fisheries sectors.

Uncertainties also exist about the potential and actual trajectories for agricultural land development and the exploitable productivity gaps. Some progress has recently been made in disaggregating crop yields and yield gaps at national and sub-national levels[92,173], but these studies have still relied on globally available census data and other relatively coarse information. Promising new methodologies for more standardized yield gap analysis have recently been developed[93,94], which will allow developing a new Global Yield Gap Atlas (www.yieldgap.org).

Long-term weather and soil data at high spatial resolution are among the most important data for supporting SAI approaches, but they represent major data gaps in many countries. Given the concerns about climate change and adaptation to it, and about precision management in relation to real-time environmental conditions, this should be among the highest priorities for the global community concerned with food security. All farmers and their advisors (and researchers) must have access to both long-term weather data and real-time weather data at a high degree of spatial resolution.

More accurate, digital information on soils and nutrients is of particular importance, because it affects decisions on fertilizer policies and management, crops that can be grown, land development strategies and investments, land rehabilitation efforts, and many other things. Progress is being made in developing digital soil information systems that combine legacy data with new remote sensing technology and fast soil analysis methods, and thus increase the spatial resolution and quality of the available information. New systems such as the Africa Soil Information Service (www.africasoils.net) will fill major gaps and will allow customized products and services for diverse stakeholders to be developed. However, they will require continuous, large R&D support and suitable business models for more self-sustained operation, and they also need to spread to all major agricultural areas in the world. On the other hand, no global nutrient monitoring system exists yet and the currently available data are highly unreliable for many countries or key components of the whole nutrient chain. Such information is critical for guiding policies as well as for tailoring nutrient management and stewardship programs so that they can achieve productivity, efficiency, social and environmental targets.

With current data and modeling, climate data cannot easily be extrapolated to provide conclusive local recommendations[174]. Therefore, a more precise agriculture will also require long-term and real-time weather information for all major crop-producing regions, with fine spatial resolution. 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 land degradation. We need to build a whole new global system for monitoring the performance of agriculture at a fine scale[143] (see Chapter 4.2.) and reward farmers who make steady progress towards improving their metrics. Our ultimate ambition should be to monitor through various means nearly every hectare of existing farmland within the next 10 years. Complete coverage of all farmland 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 the public and private sector on how to use digital technologies in agriculture.

Strengthening data collection capacity at the national level is of high priority, but it also needs to be extended to the local government level. The situation has become even more complex in recent years as a result of the resurging interest in statistics on agriculture and food systems, with many more organizations collecting their own data in an uncoordinated, non-integrated manner. Governments and international organizations such as UN organizations, the World Bank, regional development banks, and International Agricultural Research Centers have a long history of collecting data, but without proper integration of their data systems. In addition, more and more private companies and foundations as well as many NGOs are collecting data through in-house units, projects or outsourcing to third parties. By and large, it is reasonable to assume that many of the real or perceived data gaps could already be filled if ways could be found to better align these efforts, harmonize methodologies and share data. New strategies will be needed for sourcing, analyzing and sharing vast quantities of data.

Immediate steps that need to be taken to support this process start with the commitment of all partners to support the open sharing of data and learning in real-time to support rapid-cycle agricultural innovation. The G8 leaders have recently signed an Open Data Charter[v], which should be embraced by all countries and thus also become a key measure for supporting agricultural development. Governments and institutions will need to translate this into policies and incentives that ensure the timely release of important data so that new insights can be extracted to further accelerate agricultural development and also support cross-sector exchange with health, environment and finance, all of which affect the lives of the rural poor. A new paradigm is needed to reward public as well as private organizations who share research data with the broader community while acknowledging and appreciating their intellectual contribution. This is a complex challenge to face over the next 3-5 years but it is one we must collectively own and implement if we are to realize the vision of sustainable agriculture. We hope that soon there will be a coordinated global network of measurement activities that includes critical biophysical, socioeconomic, and nutritional metrics.

[v] The G8 Open Data Charter, signed June 2013, is available at www.gov.uk/government/uploads/system/uploads/attachment_data/file/207772/Open_Data_Charter.pdf.

Other useful tools can be deployed to analyze trends and inform the public, policy makers, and other actors for making the right decisions. Many useful composite indices or decision and communication tools have been proposed in recent years to score multiple functions of agriculture and food systems (Annex 3). Composite indices and user-friendly decision tools cannot replace the specific indicators needed to measure progress towards achieving targets and SDGs, but they can be valuable additional tools for policy guidance and decision-making, communication, education and concrete action. They are particularly valuable for engaging stakeholders at different levels and scales, including at local level, along the whole value chain and support system.

4. Solutions available for action

4.1. Context-specific solutions that transcend small- to large-scale farming and food systems

Farming systems are complex and highly heterogeneous at all scales, from regional and national to village or farm. So too are farming objectives, solutions and tradeoffs[175,176]. Strategies for SAI must provide viable options for farms that can produce substantial surpluses as wells as for those small farms that support the livelihood of millions of rural people. The specific policies and technology solutions for implementing SAI largely depend on the socioeconomic and biophysical contexts under which farmers currently operate, with resource endowment and market access being two main drivers across different scales (Fig. 4-1). Many other factors diversify households (size, social status, religion/tribe/caste, education, etc.), but many of these are also linked to resource endowment and market access. Different solutions are required for large farms with good market access and high input use (4), small farms with good market access and high input use (3), small farms with weak market access and low input use (2) or larger farms with poor market access (1).

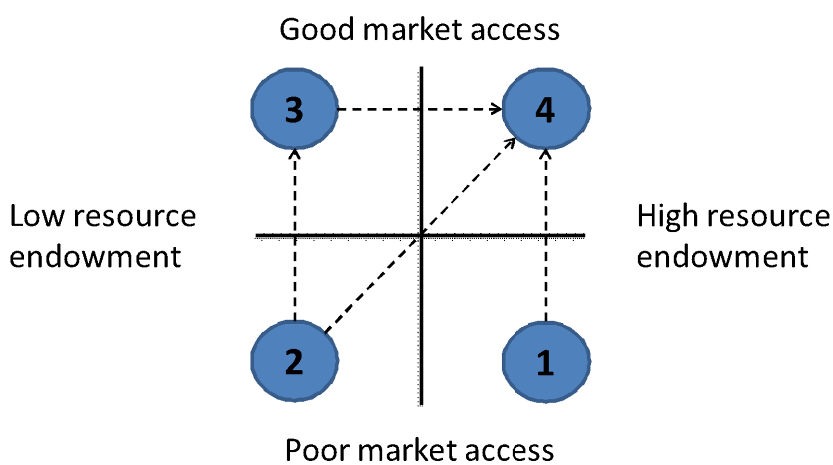


Figure 4-1. Resource endowment and access to markets are key determinants for tailoring different solutions to the local context to overcome current constraints and establish better business models for agriculture.

The real new challenge is to move to better business models by choice, beyond thousands of poor smallholders by default. At the core of devising solutions lies a thorough understanding of the socioeconomic and biophysical factors that drive the needs of farmers, agri-businesses, small entrepreneurs, consumers, and many other actors. We need to characterize and segment the "market" in order to target technologies and policies, and then "market" better technologies efficiently – through modern delivery systems. Countries need to move away from subjective mapping of factors of theorized importance to a rigorous definition of development and business domains based on quantitative data for resource endowment and market access[177]. Solutions need to be flexible in terms of offering a suite of technologies and support systems provided by different sectors in a complementary mode, with a particular emphasis on business-driven models.

Different paradigms are required for different regions (Box 4-1). 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 surplus yields 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 potential damage done to the environment.

Box 4-1. The paradigm of SAI in African smallholder agriculture[96]

Food production in Sub-Saharan Africa is not keeping pace with food demand. Yield gaps are large and pervasive in African smallholder agriculture for almost all crops in all regions. At present, most smallholder farmers are unable to benefit from potential yield gains offered by plant genetic improvement. Challenges faced include lack of access to water, nutrients, quality seeds and other inputs, small landholdings, poor soil quality and lack of capital to invest in improving soils. Coupled with intense labor demands caused by lack of mechanization, timely and better-quality field management is impeded. Irrigation, mechanization and local seed production of crops that have economical value for farmers are among the key improvements needed for increasing agricultural production in Sub-Saharan Africa, but they need to go hand in hand with better agronomy. Continued cropping without sufficient addition of nutrients and organic matter leads to soil degradation, rendering many soils non-responsive to seeds, fertilizers and other inputs. This lack of response constitutes a chronic poverty trap for many small farmers in Africa. Given the poor agricultural productivity of only 1 t/ha of cereal grain across much of Sub-Saharan Africa, the primary goal is to increase crop productivity per unit of resource invested, through carefully targeted interventions across scales. Little can be gained by trying to raise the genetic yield potential when current yields are 20% or less of what is achievable. But much can be gained by improving the genetic adaptation to local stress complexes and combining these traits with those preferred by farmers and consumers. An important fraction of the yield gap can be reduced through better agronomy (irrigation, planting dates, spacing, cultivars, early weeding, etc.) even when only microdoses of fertilizers can be applied. Sound agronomic management is a prerequisite for efficient use of quality seeds, irrigation, and nutrients. Many African smallholder farmers already practice their own forms of 'precision farming' by recognizing soil fertility gradients in their farms and fields and allocating crops and resources differently. This knowledge, combined with scientific knowledge, simple diagnostic tools such as soil test kits or leaf color charts, and solid policy support can form the basis for a broader SAI framework and its local adaptation and implementation in Sub-Saharan Africa. It needs to focus on targeted "best fit" approaches from a portfolio of options rather than pushing "best-bet" or "silver-bullet" approaches.

On the other hand, globally, there are over 500 million small family farms[w], most of which are mixed farms producing crops and livestock[178]. Half of the world's cereals are produced in these small-scale mixed farms. Smallholder farmers are often at a disadvantage in terms of available resources and accessing markets. They rely substantially on self-provisioning. It is difficult for a farming family to make a better living from growing crops or raising a few animals on a half-hectare plot with few inputs and unsophisticated technologies, unable to reach the market. Not all small-scale farmers can become large-scale farmers, but some form of aggregation of primary production and support services will be required in order to take advantage of new markets and technologies, and to transform farming into an attractive local business and job opportunity. In many developing and emerging economies where youth make up 20% of the population and youth and women's unemployment is a serious issue, new visions of smallholder farming with enhanced societal value and respect would provide a deliberate platform for generating employment opportunities and reducing migration from rural areas to urban centers.

All farmers need to be moved towards good access to inputs, markets, information and other supporting services (Fig. 4-1). Strategies that provide the needed support base as well as timely market information

[w] Farms two hectares or less in size. This includes some 280 million small farms in India and China alone.

would lower the barriers for participating in domestic and export markets. Such mechanisms include: (i) formation of cooperatives or growers' associations to increase their collective ability for effective negotiation, sharing of the cost of inputs, more efficient dissemination of new ideas and market information to farmers, and reduction of cost of certification; (ii) participation in 'outgrower' schemes organized by centralized agribusinesses where the smallholder provides land and labor in exchange for technical assistance, credit, inputs, infrastructural support and market knowledge; (iii) access to high-value crop options, niche markets and the necessary information and technologies for successful production; and (iv) regional initiatives which help to disseminate technologies, increase smallholders' market leverage and coordinate reliable supplies.

Governments, civil society, the private sector and international agencies must work together with local extension services and farmers to support the tailoring of SAI solutions to farmers' needs by improving:

- *Diagnosis:* Understand the context in which an effort or an intervention will be implemented and its links to the best available scientific and local 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 or value chain based on scientific 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, and learn to enrich the local, national and global knowledge base to influence policies that will support further implementation.

4.2. Solutions for early action

Practical solutions for transforming world agriculture need to address innovation, markets, people, and political leadership[68]. Solutions need to enable concrete action for change, towards meeting one or more of the targets defined in Chapter 3. Sharp focus must remain on solutions for poverty reduction and improving the livelihoods of rural households and communities, including more resilient crop and livestock systems that can stand extreme heat, drought, floods and other climatic extremes. Small-scale food production offers a direct route to ending hunger and malnutrition and reducing poverty, but small producers – especially if incentivized by having land tenure – are also an army of potential environmental stewards that can help protect natural resources and ecosystem services better than governments or large companies[127]. Small farmers, service providers, processors, marketers and other local entrepreneurs must be central to any investment and policy strategy that enables the development and widespread adoption of new solutions[67,73].

Equal weight needs to be given to interventions at the farm level and solutions for improving post-harvest food chains, all the way to the consumer. New opportunities exist for solutions that combine food industry and agribusiness development with the food security, poverty alleviation, and environmental agenda. The domestic private sector – composed of millions of farmers and other local businesses – is by far the biggest investor in agriculture[179]. Goals for sustainable agriculture and food production can only be achieved if domestic governments and the international community create an enabling environment that enhances sustainable and inclusive private investment in agriculture. This also requires full participation by the business community in international, national and local platforms that aim to implement the new sustainable development agenda. For small farmers to be able to step up to a higher level, key challenges to overcome include securing control over land, water and other critical resources, and gaining access to better infrastructure, inputs, knowledge and markets.

Early solutions need to focus on critical areas where improvements in crop, livestock and fish productivity and environmental performance can be made relatively quickly. Although crop[92] and livestock[45] productivity gaps vary greatly worldwide, they are particularly large in Sub-Saharan Africa[180], South Asia and some other developing regions. In many of these countries or regions within countries significant gains in productivity and resource efficiency are possible through better seeds, irrigation, nutrient management, and other agronomic measures. Policy measures have a huge impact on the success of such early actions. For example, instead of flat subsidies that encourage inefficient water use or groundwater depletion, variable policy tools could include better measurement of water consumption, variable pricing of electricity for irrigation, cross-subsidizing small holders with revenue from large holders, or targeted support for new technologies that result in higher water use efficiency without a reduction in crop yields[181].

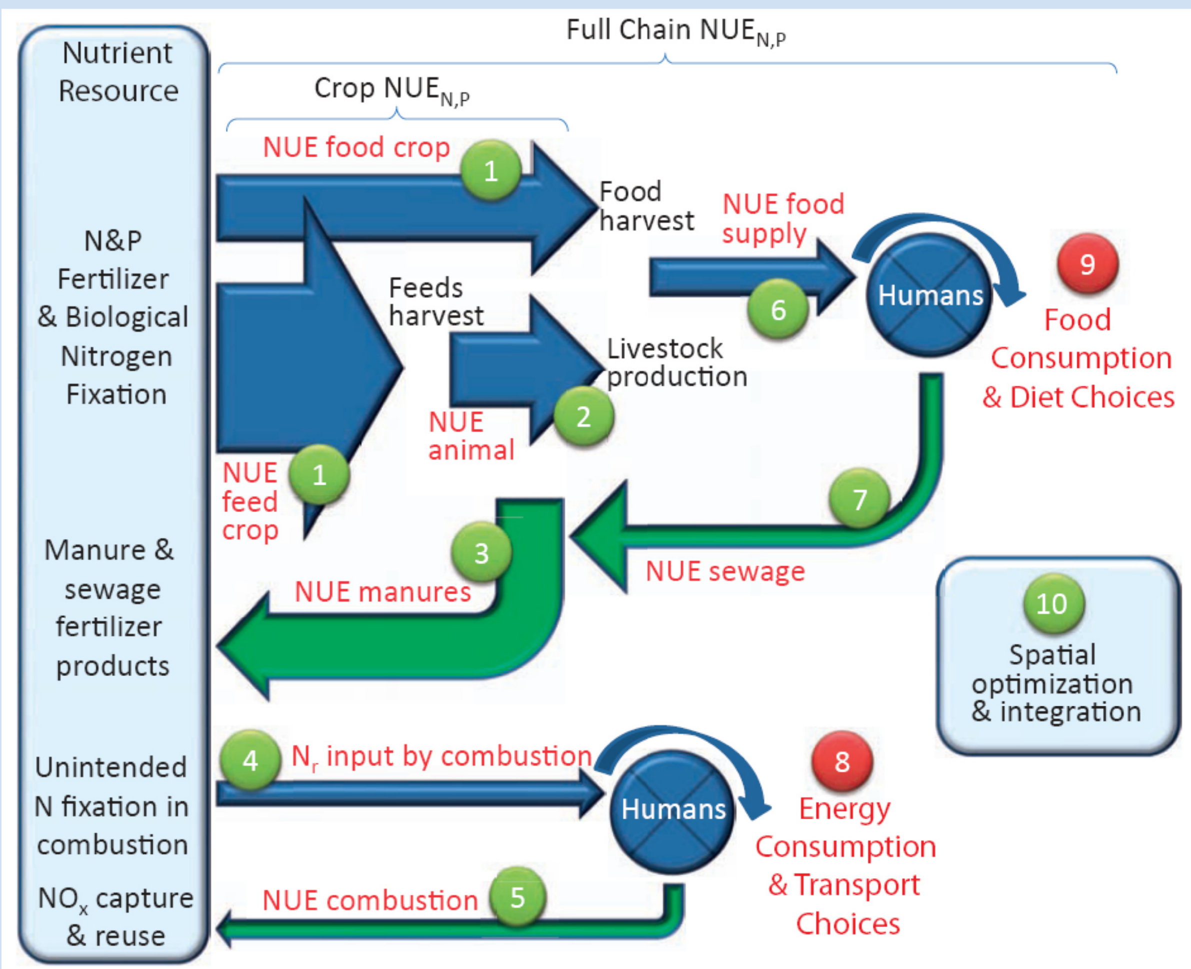
On the other hand, opportunities for improving the environmental performance of agriculture are largest in countries such as China, where input use is already high and often inefficient, particularly with regard to water, fertilizers, pesticides, and energy[182]. People are the primary agents of change. They must be at the center of solutions for concrete action at national to local scales. On one hand we need to strive to change the behavior of everyone, from the food producer to the consumer, including politicians and business executives. On the other hand, we need to provide new opportunities for people - women and youth in particular - to become part of a new sustainable development movement through attractive job opportunities. That requires equipping people with the knowledge, skills, new tools and information needed to enact change.

An important way to solve problems is through practical initiatives involving new technologies, business models, institutional mechanisms, and/or policies that are promising for early action, can take place in any country, and can also generate learning elsewhere. They need to address various components of SAI and its enabling systems (Fig. 2-1), but many are connected and must be integral parts of a systematic approach to SAI, from food production to consumption (Box 4-2). Many solutions will have to be integrated initiatives designed and implemented in a specific development or landscape context, in response to the most relevant national and local challenge domains for agriculture. Nevertheless, we should also recognize those few interventions or innovations that could indeed trigger transformative changes in farming or a whole food chain over a relatively short period.

Below we provide **examples of solutions for early-action**, i.e., interventions that could be of high priority for many countries in the coming 5 to 15 years. We do not aim to provide simple recipes or policy strategies with specific priorities for countries or regions. Instead, our examples are a basket of options for countries to consider and adapt to their specific needs. They can be further prioritized and customized based on cross-sectoral benefits, scalability and wide applicability, novelty, feasibility, learning by doing, comprehensive vetting and sponsorship. Countries need to be committed to implement these solutions themselves, but with support as required from other countries and international agencies. Technology spillover and many forms of between, cross-country and cross-regional learning should play a major role in guiding countries and helping them to move faster. International action networks such as the SDSN will promote selected **solutions initiatives** for early-stage demonstration, development and scaling up.

Box 4-2. Ten key actions for improving nutrient use efficiency in food systems

Improving the full-chain Nutrient Use Efficiency (NUE) of nitrogen and phosphorus, defined as the ratio of nutrients in final products to new nutrient inputs, is a central element in meeting the challenge to produce more food and energy with less pollution and better use of available nutrient resources. Nutrient flow is a cycle from resources through stages of use (blue arrows) and recycling (green arrows). The system is driven by the 'motors' of human consumption (red), which are thus also a key part of the solutions needed for achieving future nutrient targets. The poorest need to be allowed to increase their food and other nutrient consumption, while the richest must realize that it is not in their own interest to over consume. There are significant differences in the cycles of nitrogen, phosphorus or other nutrients among and within countries that need to be taken into account in determining specific targets and interventions. Hence, the targets for nutrient use and NUE will vary among countries and so will the pathways for achieving them by addressing any of the specific components of the full-chain NUE relative to their current state. Possible actions include (numbers in the graph): 1 Improve NUE in crop production; 2 Improve NUE in animal production; 3 Increase the fertilizer equivalence value of animal manure; 4 Low-emission combustion and energy-efficient systems; 5 Develop NO_X capture and utilization technology; 6 Improve efficiency in the fertilizer and food supply and reduce food waste; 7 Recycle N and P from waste water systems; 8 Energy and transport saving; 9 Lower personal consumption of animal protein; and 10 Spatial and temporal optimization of nutrient flows. Of the 10 solutions proposed, the first three are directly related to agricultural systems management. Specific targets and indicators can be defined for each of these steps.



Source: Fig. 6.1., Sutton, M.A. *et al. Our nutrient world: the challenge to produce more food and energy with less pollution*. (Center for Ecology and Hydrology, Global Partnership on Nutrient Management, INI, Edinburgh, 2012).

New, productive crop varieties for the poor
Main contributions: Targets 1a, 6a, 6b, 9a

Crop yield growth rates in many smallholder farms remain too low and farmers often experience periods of food or income insecurity due to yield losses caused by abiotic and biotic stresses. Every farmer should have access to affordable, quality seed from a wide range of well-adapted crop varieties or hybrids through government, private sector and community seed systems. Enhanced breeding methods such as marker-assisted precision breeding or genetic engineering[x] can be deployed to speed up the rate of genetic gain, shorten the time it takes to develop new varieties, and breed new varieties more precisely for specific environments and market segments, thus better meeting farmers' needs[99,100,109]. This requires investments to transform public and private sector breeding pipelines of major food crops into faster, more efficient, product-oriented breeding pipelines. Full advantage can now be taken of wider genetic diversity, genome sequence information, genome-wide molecular markers, low-cost genotyping platforms, rapid generation advancement, breeding population development technologies, better phenotyping and variety testing methods, and breeding information management tools.

Box 4-3. Stress-tolerant rice varieties as a climate-smart solution for the poor

The International Rice Research Institute (IRRI) and its national partners in Asia are developing a new generation of rice varieties that are tolerant to submergence, drought, heat, salinity and combinations of those. In the early 1990s, using a flood-tolerant landrace from Eastern India, scientists at IRRI and the University of California-Davis discovered a major locus on chromosome 9 of the rice genome – later called the SUB1 gene – that allows rice to endure complete submergence for up to 2 weeks, thus greatly reducing the risk of flood damage, which threatens 20 million hectares of lowland areas in Asia. Subsequent fine mapping of the gene and progress in DNA marker technology enabled marker-assisted breeding of high-yielding rice varieties with flood tolerance and yield advantages of 1–3 t/ha demonstrated in farmers' fields. The first new variety, Swarna-Sub1, was developed in 2006, followed by official release in 2009. Quality seed was rapidly multiplied and disseminated through a large network of over 400 hundred public, civil society and private sector partners in India, Bangladesh, and Nepal, supported by national policy makers and international donors. By 2013, about 4 million rice farmers in these three countries grew the new flood-tolerant rice[183]. Similar approaches are being applied to breeding drought-tolerant rice, showing consistently large yield advantages of 0.5-1.5 t/ha[99]. New breeding products combine drought with submergence tolerance, heat with drought tolerance, or submergence with salt tolerance through marker-assisted selection, which will provide "free" crop insurance for farmers[184].

Intellectual property regimes and national variety release guidelines need to be modernized, harmonized and incentivized to rapidly release new varieties and encourage investment in breeding and seed businesses. Seed laws and policies need to enable and support a vibrant public and private seed system, including many small- and medium-size companies and seed producer groups. Well-coordinated global crop improvement networks can further accelerate progress in genetic gain by increasing the resolution and precision of environmental information, working across key domains and hotspots for a range of biotic, abiotic, and socio-economic constraints, and sharing knowledge, genetic and other resources in 'open source' breeding platforms[185]. Countries with insufficient breeding capacity would gain from progress being made in other countries, thus enabling farmers worldwide to increase yields and reduce the risk of yield losses due to drought, high temperatures, flooding, salinity, diseases and

[x] Marker-assisted selection is a conventional breeding method in which the selection process is accelerated by detecting the presence of desired traits (DNA sequences) through molecular markers or whole-genome analysis. In contrast, genetic modification (GM) involves the direct transfer of genes from one organism to another, including genes from other species.

insect pests. Among the most successful examples so far has been the development and deployment of a new generation of stress-tolerant varieties for rainfed lowland rice areas in Asia and Africa (Box 4-3).

More nutritious staple food crops

Main contributions: Targets 1a, 5c

A few staple food crops dominate the food intake of 2 billion people suffering from undernourishment caused by iron, zinc, vitamin A and other deficiencies. Achieving better nutritional balance involves a wide range of measures, diversification of agricultural systems (crops, livestock and fish products), external mineral and vitamin supply, optimal feeding and caring practices, breeding of more nutritious crops, agronomic biofortification, and other measures[186]. Supplementation programs or the promotion of home gardens or livestock and fish have limits in terms of reaching all of the poor; many do not even have the land or other resources to grow their own more nutritious food. While the health benefits of a balanced diet are clear, biofortification – the enrichment of staple food crops with micronutrients, vitamin A or other enhanced nutritional traits through breeding or fertilizers – is another effective strategy for overcoming specific nutritional deficiencies in rural populations in developing countries. It reaches down to the lowest income levels and elevates the base level of nutrient intake, thus also making many other interventions more successful, and helping to eradicate hidden hunger by 2030. Even small increases in the protein, mineral, or vitamin content of staple crops can make a significant difference in nutrition and health. Significant progress has been made in recent years to breed more nutritious food crops, through both conventional breeding and genetic modification (GM). Promising examples include vitamin A-enriched sweet potatoes (orange sweet potato), rice (Golden Rice), maize and cassava; high-zinc rice and wheat; and high-iron beans, pearl millet and rice. Several conventional varieties have already been released and the results of efficacy and effectiveness studies have confirmed substantial nutrition benefits[187]. Countries, civil society and international agencies should take measures to accelerate progress in breeding, release and distribution of biofortified crop varieties. Breeding programs need to include nutrition traits in their standard product profiles and variety evaluation schemes so that nutrition traits become part of mainstream breeding. This is a departure from the past focus on long shelf life, standard color and shape which is often achieved at the expense of nutritional content as there is often a trade-off between the various traits. Breeders need to take full advantage of new genomics, biotechnology and breeding technologies to achieve quantum leaps in micronutrient and vitamin enrichment of food crops targeting the poor. Deployment of these varieties through local seed systems needs to be accelerated to ensure that quality seed is available and affordable. In addition to breeding, micronutrient fertilization is another highly successful strategy to fortify crops agronomically. By adding, zinc, selenium or iodine to conventional fertilizer blends, it is possible to not only boost productivity through yield gains but also to eradicate deficiencies in humans[188].

New models for agricultural extension

Main contributions: Targets 1a, 6a, 6b, 8b, 9a

Many unexploited income, productivity and resource efficiency gaps can be closed through accelerating the transfer of new knowledge and technologies, enhancing access by farmers to markets and information, facilitating better interaction among farmers and knowledge providers, and assisting farmers and small businesses to develop their own technical, organizational and management skills and practices. This is the essence of good agricultural extension and it has been the driving force for productivity enhancements in many developed countries[53]. In crop production, for example, it requires systematically implementing programs aimed at improving farmers' skills in practices such as cropping systems choice, land preparation, choosing the right seed, planting, water and nutrient management, control of pests, diseases, and weeds, machine operation, harvest and postharvest operations, record keeping, farm business management, and information technology. Throughout the world, every farmer should have access to good-quality extension and advisory services provided by the public sector, private companies or consultants, NGOs, or farmer organizations. All of them can play complementary roles. Unfortunately, agricultural extension systems in most low- and medium-income countries are weak, both in term of outreach capacity and the quality of service provided. They often lack incentive schemes and mechanisms for professional training for agricultural advisory workers. Different sectors rarely work together.

Demand-driven, pluralistic advisory and extension systems with motivated, skilled professionals and effective use of modern information-communication technologies (ICT) will be required for making SAI a reality, in every farm[189]. Depending on the most appropriate local extension model, professional crop advisers, government extension agents, farmer facilitators, community knowledge workers, as well as sellers of agricultural inputs need to become trusted expert contacts for farmers. A new generation of agricultural knowledge workers must have the necessary technical, interpersonal and communication skills, professional certification and continued education, means of transport, technical backstopping, and more. They also need to have clear incentives to help farmers succeed[53]. To both generate new knowledge and provide local agriculture solutions for farmers they need to have strong links to and understanding of adaptive research within relevant agro-ecologies. They also need to be in full command of soft facilitation skills, modern decision tools, and information technologies (mobile/smart phones, internet, social media, participatory video, remote sensing, soil and weather data, etc.)

Realizing this vision will require transformative institutional changes of current agricultural extension systems in most countries, including a greater role for the private sector, as well as complementary changes in agricultural research, especially greater capacity in adaptive research linked to extension capacity[189]. Many new models are currently being piloted. First lessons are being compiled by global and regional platforms for rural advisory systems such as MEAS (www.meas-extension.org/meas-offers/case-studies)[190] or GFRAS (www.g-fras.org/en). Innovations include demand-driven and market-oriented mechanisms to link farmers more directly to improved technology, new business models and product markets, such as the China Agriculture Extension Special Task Force or FIPS-Africa (http://fipsafrica.org), in which self-employed village-based advisors also participate in profit-sharing schemes with farmers. Following a multi-technology approach, such practitioners must have good command of both technical and entrepreneurial skills. There is also significant potential for linking agricultural extension with other sectors, for example nutrition and health, education, finance, and government services. The key to success will be to create scalable, self-sustained business models in which a new generation of proud and skilled agriculture professionals can earn a good living by serving farmers, entrepreneurs and others involved in agricultural value chains.

Nutrient management and stewardship – from science to local solutions
Main contributions: Targets 1a, 6a, 6b, 8b, 9a

Improving nutrient management is a central element in meeting the challenge to increase food production, increase farm incomes, improve soil quality, reduce nutrient losses to the environment and protect natural ecosystems. Both governments and businesses play an important role in this process. Science-based principles for integrated, site-specific use of fertilizers, organic materials and other nutrient sources have been developed through research. Site-specific nutrient management in crops such as rice, wheat and maize has shown large benefits in terms of yield, farm profit, increased nitrogen use efficiency and better nutrient balances[191-193]. Mobile phone and web applications have been developed for use by extension workers and farmers in many countries, e.g. NM Rice (www.irri.org/nmrice). Integrated Soil Fertility Management (ISFM) strategies that make use of mineral fertilizers and locally available organic amendments but also promote other good management practices are a key to increasing agricultural productivity and improving poor soils in Sub-Saharan Africa[176,194]. Countries, businesses and international donors should invest in solutions initiatives that seek to systematically improve nutrient management for increased crop production, sustainability and associated benefits, such as the 4R Nutrient Stewardship programs (Box 4-4).

Box 4-4. 4R Nutrient Stewardship

Enhanced nutrient stewardship plays a critical role in increasing crop production and sustainability. It is the foundation for improving farm incomes, and in turn, improving food and nutritional security, education, healthcare, local employment and environmental investments. In cases of low nutrient use efficiency and higher crop production it supports grower efforts to increase crop uptake of nutrients while continuing to increase crop yield, profitability and environmental performance. 4R Nutrient Stewardship (www.nutrientstewardship.com) provides an action framework for improving the economic, social and environmental performance of nutrient use. Applying the right source of plant nutrients at the right rate, time, and place within a cropping system is the basis for nutrient stewardship. These four 'rights' are necessary for sustainable management of plant nutrients using both organic and inorganic amendments, and when used with other agronomic best management practices (e.g., improved seed, planting density, etc.), allow growers to achieve economic, social and environmental goals[195]. Performance improvement goals are specific to the region (increased yield, improved nutrient use efficiency, reduced runoff and leaching, etc.) and are achieved through implementation of regionally specific best management practices. Implementation involves participatory learning through continuous assessment of impacts, and feedback from researchers, extension workers and growers in a process of iterative enhancements. Improving nutrient use among farmers supports local and regional activities on improving environmental goods and services such as water quality, but also strengthens local agri-businesses that provide inputs, dispense agronomic advice and support the local economy. Model sites are being established in North America within key watersheds to advance nutrient stewardship programming and a research fund has been established to advance the system. In Kenya, a model site has been established to create a 4R nutrient stewardship system and enabling extension for small maize producers. The system will be implemented in pilot areas with the goal of increasing yields, improving soil quality and supporting the development of agribusiness. An iterative implementation and scaling model will be used to customize the solution to regional and local needs using model sites. All information will be open source, allowing interested stakeholders to adopt and adapt the solution to their local situation. Additional private and public partners are being sought to expand pilot sites, extension staffing and expert farmer programming, but also scale up to include new crops, other best management practices, and the use of digital technologies to support local adoption and the sharing of information globally.

Micro-irrigation for smallholder farmers

Main contributions: Targets 1a, 6a, 6c

Many smallholder farms in Sub-Saharan Africa, Asia, and other regions are trapped in poverty and experience periods of food insecurity due to low cropping intensity and productivity caused by water stress. Irrigation is a key entry point for doubling or tripling crop yields and enabling diversification of cropping systems. Large-scale irrigation systems are capital intensive and restricted to lowland areas with suitable conditions. Solar-powered drip or other micro-irrigation technologies, on the other hand, can be customized to meet the needs of small farmers operating in diverse environments with limited capital. Micro-irrigation systems precisely deliver water, nutrients and other inputs directly to the root zone, resulting in high yields and high efficiency of these inputs. Equipped with additional filters, these systems can also supply clean drinking water. Smart-metered, local solar and wind power utility models can provide the electricity needed for irrigation pumps, as well as local households, schools, and small village enterprises, including processing or storing of food. Demonstrated impacts include improved food security and nutrition, increased incomes, reduced poverty, and new local business opportunities and jobs[196,197].

Modern low-pressure drip or other micro-irrigation systems are modular and can be designed to meet varying local needs, ranging from a small family plot to village or community-scale production. A stage-wise introduction and scaling up strategy includes a thorough analysis of the biophysical and socioeconomic environment for technology design and business model development, financing, business development, training of farmers and professionals, and linkages to input suppliers and markets. Solutions for harvesting rainwater or accessing and storing available surface and groundwater water need to be adapted to the local situation. Young agricultural professionals and technicians need to be trained and have the right incentives to provide professional services to farmers as a business. To minimize risk and enhance food security, drip-irrigated, intensified cropping systems should include staple food crops and crops with high nutritional and market value (e.g., vegetables, fruits). Intensive, diverse, all-year-round cropping is scheduled by the local community according to water and electricity needs by different crops and users. Farmers may also form new cooperatives or other small enterprises through which drip irrigation agriculture is done. Contract farming can become an integral part of such new value chains. Services, maintenance and inputs are provided by local utility and service company professionals, supported by public sector research and extension workers. Local workshops for small machinery, pumps, repair and maintenance can create additional jobs. Implementation requires low-interest capital from various sources as well as financing through pay-per use models for both electricity and water. Smartphones linked to the internet provide access to real-time weather and market information and are also used for real-time water and electricity monitoring, and customer management (contract tracking, billing, and payments).

Investing in livestock markets
Main contributions: Targets 1a, 5c, 6a

Livestock account for 40% of agricultural GDP in developing countries and four of the five highest traded agricultural commodities are livestock products, but the sector underperforms in terms of its contribution to food security, poverty reduction and livelihoods of smallholder producers. By investing now in the promotion of livestock enterprises and value chain development, national governments and the donor community could pave the way for the emergence of a livestock industry that will sustainably respond to national food security needs while staying inclusive of small livestock keepers. National livestock strategies promoting enterprise and value chain development should address four main constraints[198,199]:

1) Strengthening the institutions governing livestock product value chains: Foster the emergence of livestock commodity associations where representatives from all the stakeholders in particular commodity chains sit together to resolve common problems for the whole chain. The South African Red Meat Industry Forum is a successful example of this.

2) Consolidating the enabling environment for livestock businesses: This includes a) developing and enforcing a legal framework for livestock sector businesses, b) development of appropriate road, electricity, water, information and communication technologies and slaughtering and market infrastructures, c) facilitation of international trade by, for example promoting “itinerant” customs controls across the country rather than only at ports of entry and aligning trade regulations across countries, d) strengthening animal health systems and e) setting up livestock product quality and safety standards which are adapted to the country’s situation and its smallholder farmers and which are also trustworthy for regional foreign buyers.

3) Implementing targeted public incentives to encourage investment in livestock enterprises: Establish a government investment fund targeting the livestock sector and which can contribute to funding investment activities by farmers, SMEs and larger agro-industries and to help secure loans from private banks or microfinance institutions.

4) Developing the business management capacities of livestock value chain stakeholders: Livestock sector development will not happen without capacity building of smallholder farmers and SMEs in business and enterprise management. Sharing of innovations across the livestock product (and other agricultural) value chains is also essential for market-led agricultural extension and supply chain management. Public extension services are often not well equipped to implement such capacity development activities effectively, but public funds can help increase the budget of NGOs, industry bodies and farmers' organizations to implement capacity development activities that are in line with wider livestock sector development objectives, agreed upon by the whole industry in a consultative process.

Livestock vaccines
Main contributions: Targets 1a, 5c, 6a

Medical and veterinary vaccine inventions are among the most cost-effective disease control interventions ever deployed. They have enabled the global eradication of two lethal diseases, e.g., smallpox in humans (1979) and rinderpest in cattle and wild ungulates (2011). Vaccines against livestock diseases have the power to reduce livestock mortality, sustainably increase productivity, increase food and nutritional security, enhance the livelihoods of the poor and help developing economies grow. Extensive quarantine, diagnosis and slaughter of livestock are not sustainable disease control options in developing countries. Vaccines are essential in preventing the spread of disease. Diseases of tropical origin are now threatening developed countries. For example African Swine Fever has reached Europe and is threatening the pig industry there.

Despite the importance of vaccines, many of the diseases that affect livestock in developing countries are neglected. There is an under-investment in this critical area of livestock agriculture. The situation is exacerbated by a general lack of capacity to undertake early phase research in developing countries and a lack of biotechnology related enterprises. Priority livestock diseases include African Swine fever (ASF), contagious bovine pleuropneumonia (CBPP), East Coast fever (ECF), peste de petits ruminants (PPR) and Rift Valley fever (RVF). The latter is a zoonotic disease that can be transmitted from livestock to people. Live pathogen based vaccines exist against CBPP, ECF, PPR and RVF. For ASF there is no vaccine and preventing the spread of virus is the only realistic method of disease control.

Although the existing vaccines are often sub-optimal in nature and require cold chain facilities for delivery, they can be used until more effective vaccines are developed. With advances in molecular techniques, investment in the development of a new generation of subunit vaccines and vaccines that are thermostable could have huge rewards in the next 10 years. This would also help spawn a new generation of scientists to continue battling on the front lines of the ever-evolving arms race between health and disease.

Doubling animal productivity with better use of crop residues
Main contributions: Targets 1a, 5c, 6a

Crop residues such as straws, stover and haulms form the basal diet of hundreds of millions of livestock in smallholder systems throughout developing countries. These feeds have low to moderate nutritional value but even moderate improvements in their quality have substantial effects on livestock productivity - a one percent increase in digestibility results in 6 to 8% increase in livestock outputs. In most crops different cultivars have different nutritive values. For example, digestibility varies in cowpea, sorghum, pearl millet and groundnut by 3 to 5 percentage units and in rice straw by 10 percentage units. These differences can be exploited when farmers choose cultivars with better nutritive value, without detriment to grain or pod yields. Fodder traders are well aware of these important differences in nutritive value. For example in sorghum stover traded in India, a one percent difference in digestibility was associated with a price difference of 5%. Feeding trials showed that feeding sorghum stover with a digestibility of 52% compared to 47% as part of a mixed diet increased daily milk yield in buffaloes from 10 to 15 kg. Studies of the Indian dairy industry show that improving the basal diets of crop residues, coupled with feed processing and fortification could double the milk yield per animal without requiring more grain that can be directly used for human consumption.

With the rising availability of fast, cheap laboratory methods all new varieties of crops should be screened for nutritive value of crop residues and this information made available to farmers along with data on yield, disease resistance, etc. so that they can make informed choices about the varieties that they select for growing. Indian sorghum breeders have pioneered this approach with nutritive value of crop residues being one of the criteria used for release of new varieties. Extension of this to the release criteria of crops in other national programs should be a priority. Fodder quality traits, such as digestibility and nitrogen content should be incorporated into crop improvement programs – this can be done without impacting grain yield. Targeted genetic enhancement for food and feed/fodder traits using recurrent selection, hybridization, marker assisted selection and QTL identification and backcrossing should be mainstreamed into crop breeding.

Climate-smart agriculture

Main contributions: Targets 1a, 6a, 8b, 8c

Climate-Smart Agriculture is not a single, specific agricultural technology or practice that can be universally applied. It is an approach that requires site-specific assessments to identify suitable agricultural technologies and practices that aim to increase productivity in an environmentally and socially sustainable way, strengthen farmers' resilience to climate change, and reduce agriculture's contribution to climate change by reducing GHG emissions and sequestering more carbon[200]. Typical CSA investment areas include a) implementation of sustainable land management practices (e.g. conservation agriculture[y], agroforestry, integrated livestock management, and water harvesting), b) climate risk management (e.g., drought-tolerant varieties, early warning systems, climate forecasts, and use of ICT tools for disseminating weather information), and c) transformation of whole production systems. Innovative policy instruments and financing mechanisms that link investments from the public and private sectors are key components for implementation. CSA includes activities that communities, villages, districts and higher government levels can take, for example to provide a back-up in case of crop or animal production failures.

Implementing CSA approaches is often challenging, partly due to a lack of tools, technology and data (especially down-scaled weather data) to support the integration of multiple interventions at the farm level. Climate-smart interventions are highly location-specific and knowledge-intensive. Considerable efforts are required to develop the knowledge and capacities of a wide range of stakeholders. Rainfall is

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[y] Most efforts to date in developing countries have promoted conservation agriculture as a package of three practices: minimum disturbance of soil (zero, minimum, or reduced tillage); retention of sufficient crop residue to provide surface coverage; and diversified cropping patterns that usually also include a legume. Except for North and South America, widespread adoption of this package has not yet occurred, but there is evidence for adoption of one or two of these components in some areas in Sub-Saharan Africa or South Asia[201].

often the greatest production risk farmers face. Instruments to manage this risk include weather index insurance, drought tolerant and water-efficient varieties, conservation agriculture practices, water harvesting and supplemental irrigation technologies. New commercial micro-insurance models are emerging that hold promise when integrated with input credit programs and local weather stations to validate low rainfall events and trigger payments. One such example is the Kilimo Salama (http://kilimosalama.wordpress.com) program in Western Kenya that uses an existing mobile money platform to make payments to eligible customers. The integration of satellite radar and local automated reporting rain gages will be critical to support weather indexed credit and insurance. In the MasAgro (http://masagro.mx/index.php/en) program in Mexico, federal and state agencies are aligning policies and incentives to enhance the adoption of conservation agriculture practices for wheat and maize production, for increased productivity and resilience to weather variability, especially rainfall. Another example are policies that provide incentives to reduce GHG emissions associated with rice in Vietnam.

Increasing resilience to pests and diseases

Main contributions: Targets 1a, 6a, 9a

As cropping systems intensify, the potential for losses due to insects, diseases and weeds (together termed "pests" hereafter) will increase if it is not actively managed. This may be exacerbated by the increased climate variability that is predicted over the next four decades, which could favor the rapid buildup of pests and disease populations. Pest risk will be compounded by increased movement of humans, food and natural products among countries. Over the past four decades, integrated pest management (IPM, http://pesticidestewardship.org/ipm) has emerged as a widely accepted approach to manage pests using host plant resistance combined with cultural, biological and chemical control methods[202].

Genetic resistance can be effective at the variety, population and landscape levels in reducing risk related to pests and other stressors. When resistance is built into the genetics of the crop or livestock variety, it is easily replicated and distributed to and among farmers. Breeding resistance traits into commercial crops and livestock has become more effective with the advent of modern molecular tools that enable scientists to identify the different versions of a gene (called "alleles") responsible for resistance and track their integration with other resistance traits into a single variety. For some pests, natural diversity does not provide adequate control, which may require genetic engineering solutions. For most pests, however, natural diversity for resistance exists and can be utilized through breeding and population management. Cultural controls include crop rotation management, intercropping, agronomic practices that improve the health of the plant or animal to naturally resist or tolerate attack, or the management of habitat reservoirs. New "ecological engineering" approaches aim to support populations of biological control agents that can regulate pest populations below economic damage levels. One example of this is the "Push-Pull" mechanism used in Kenya to control stemborers and Striga in maize. Desmodium (a perennial legume) is intercropped with maize to "push" or repel stemborers and to suppress Striga, and Napier grass is planted outside the field to "pull" or attract stemborers away from the maize crop[203]. Both Desmodium and Napier are valuable fodder crops for the Kenyan smallholder dairy industry.

Given the knowledge intensive nature of many IPM practices, few examples of wide-scale, sustained adoption exist. However, ICTs are now improving access by researchers and extension agents to pest and disease diagnostic tools. Along with improved population modeling and weather data, IPM is now well positioned to leverage digital platforms to support frontline extension agents and farmers in implementing preemptive management practices. Improved weather data will be required – especially for regions with the most dramatic weather variability. ICT tools and community-based crop clinics such as the Plantwise initiative of CABI (www.plantwise.org) and its partners are already offering improved access to a growing knowledge base for pest and disease management solutions. Policies that support integrated approaches to pest and disease control will be important to avoid the unintended consequences experienced 50 years ago with the introduction and over-reliance on synthetic pesticides as a 'silver-bullet' for control. Most importantly, input suppliers, extension professionals and farmers need to be trained well in all aspects of modern pest management, including pesticide stewardship (www.croplife.org/crop_protection_stewardship) to minimize environmental or health risks.

Innovative smallholder technologies to increase crop value, reduce postharvest losses, and improve food safety

Main contributions: Targets 1a, 6a

Because farmers are often unable to dry, store and process their produce, losses are high and there is widespread contamination of foodstuffs with microbes and mycotoxins. For example, most vegetables and high-value food crops are at peak quality at harvest but start to deteriorate soon afterwards. Moisture loss and physical damage during harvest, packing, storage and transportation causes losses of 20 - 80%[204]. The loss of produce volume, nutritional content and quality mean that consumers pay more for products which are less beneficial to their nutritional security. Reducing postharvest losses of these products will increase the incomes of the producers and the availability of micronutrients for all. For starchy staples such as root, tuber and cereal crops, as well as for many legumes, proper drying and storage is also critical to avoid the buildup of toxic compounds such as aflatoxin and fumonisin, which are produced by molds.

Various postharvest handling methods are already available to help deliver more produce of better quality to the point of sale. The methods reduce moisture loss and physical damage at every step along the chain from field and harvest to consumers. Growers should use the most appropriate crops to withstand the local environment, transportation and market challenges[205]. These varieties must be well adapted to biotic and abiotic constraints, and have morphological and physiological traits to assure the produce reaches the consumer in optimum condition and is acceptable. Best practices must be used: harvest at optimum maturity and at cooler times of the day and keep produce in the shade to reduce temperature and moisture loss; use harvesting tools and storage containers that do not inflict unnecessary damage to the produce; grade the produce to remove damage or diseased materials to minimize microbial spoilage; and clean and pack into uniform lots to attract higher prices. In many developing countries, keeping produce cool is a big challenge: simple evaporative coolers are already available, and mechanisms to adapt air-conditioners to reduce temperatures further have been developed[206]. Other postharvest techniques which can suit smallholder producers are various drying techniques to retain quality and improve shelf-life, modified atmosphere packaging, and food processing to increase shelf-life, retain nutrients and add value.

To reduce postharvest losses, growers and processors must be able to know what economic losses occur and are avoidable. The information must help guide stakeholders, in both the public and private sectors, to identify constraints and opportunities. Active participation of all stakeholders is needed to identify the best postharvest management packages. Policy constraints also need to be addressed – all in the context of delivering safe, health-promoting foods to consumers with minimal wastage. Preferred postharvest practices must be validated; profitable technologies will encourage confidence among the growers and value-chain actors to adopt the technologies. Further mechanisms for adding value may include certification, further cleaning and produce sanitation, and preparation of vegetables ready for cooking to meet the needs of busy urban consumers who need to save time in food preparation. Centers of excellence for postharvest management may be an ideal mechanism to provide necessary advice, services, tools and materials to empower growers and other actors along the value chain to make greater positive impact on their health and livelihoods by delivering more and better quality produce.

New business models for smallholder farming and marketing
Main contributions: Targets 1a, 6a, 6c, 8c

Where structural transformation processes in urban and rural areas proceed rapidly, traditional smallholder farming will more and more be supplemented or replaced with outsourcing of farming operations, the formation of small and medium-size farmer cooperatives or agribusiness enterprises, and contract farming[207]. Value chains for major agricultural commodities will become more tightly integrated because processors and consumers demand more information and control over how food is being produced, with supermarket chains playing a particularly important role. For farmers this is a chance to connect with rapidly growing domestic and export markets and thus become more direct beneficiaries of competitive food systems. The food industry in particular has increased investments in direct-sourcing of agricultural produce from small farmers worldwide, a trend that is expected to continue due to increasing industry and consumer demands for tracing food and meeting certified as well as non-certified production standards (e.g., Good Agricultural Practice www.globalgap.org or the SAI Platform www.saiplatform.org).

Many countries and businesses are now experimenting with such new forms of market-oriented smallholder farming. They are often linked to supermarkets and food processing chains and can lead to substantial income gains for the participating farmers as well as better access to inputs, services and new technologies[207,208]. A quiet revolution towards more vertical integration of value chains is already occurring in many countries of Asia, where urban areas typically account for half the population and two-thirds to three-quarters of its food demand (Box 4-5)[79].

Structural and value chain transformations of this nature could become key vehicles for improving the income of small farmers, creating attractive jobs in rural areas, and providing affordable, safe, nutritious food to urban consumers. They also provide entry points for reducing food waste, particularly food which perishes between farm and market in the developing world. They are opportunities for solutions that combine food industry and agribusiness development and market competitiveness with the food security and poverty alleviation agenda. More and larger-scale pilots are needed to develop inclusive and sustainable business models for such a transformation of smallholder farming, including good compliance mechanisms[80,209].

Box 4-5. The quiet revolution in staple food value chains in Asia[79]

Transformational changes in rice and potato value chains are occurring in Bangladesh, India and China. This includes a rapid rise of supermarkets, modern cold storages, large rice mills, and commercialized small farmers using input-intensive, mechanized technologies. Although there is great heterogeneity in farm sizes and distribution of non-land assets, all farmers, regardless of how small their plots are, are commercializing and benefitting. Markets for farm machinery, water and land are active. Through mobile phones farmers are much better informed on what, how, and for whom to produce. In the midstream segments of the value chain, driven by the private sector, rice mills are modernizing and cold storage facilities for potatoes have expanded rapidly to meet the demands of new off-season urban markets. The rise of cold storage has brought higher incomes for potato farmers and all-season access for potato consumers. Processors now buy directly from farmers so they can do their own branding and packaging, as supermarkets have penetrated urban food retail, shifting from loose, unbranded staples to packaged, branded staples with traceability in the supply chain. Off-farm components of the value chains account for 36-40% of the total margins in these new rice and potato chains, illustrating the importance of increasing the productivity of processing, storage and distribution of food.

Digital agriculture
Main contributions: All targets

Digital technologies will be a key enabler to grapple with the complexity of SAI and taking it to scale. Mobile phones, interactive radio, video and internet can enable farmers to access location-specific and timely recommendations that are actionable, but also to contribute to gathering large-scale datasets on the performance of agricultural options (varieties, planting dates, etc.) Crowd-sourcing can help fill data gaps and thus improve the tailoring of recommendations. Mobile technologies in particular are a vehicle to not only integrate improved varieties, agronomy and policies to support food systems, but also as the mechanism to integrate other key services such as credit, insurance, education and health. Digitally-enabled technologies can drive transparency that in turn supports accountability and ultimately leads to good governance – an essential ingredient for development. Governments need to embrace the era of digitally-enabled exchange of information and learning to accelerate the pace of development, democratize information, and empower farmers, consumers and investors to make informed choices. Strong public-private partnerships will be required to realize the full potential of digital technology along value chains. Examples of digital agriculture applications include:

- National and sub-national scorecards that track key indicators related to food security, nutrition and environmental sustainability of national food systems.
- High-resolution satellite imagery to support land tenure processes so farmers can invest with confidence in improving their land.
- Digital data, maps and spatial application services for deriving customized products according to user specifications. Examples include the Global Yield Gap Atlas (www.yieldgap.org) or the Africa Soil Information Service (www.africasoils.net).
- Data platforms to support farmer research networks conducting simple experiments on large scales to support improved deployment of germplasm and other agricultural options.
- Smartphone platforms for location-specific delivery of crop status information and forecasts, based on high-resolution, real-time crop monitoring by satellites, cloud-based processing, weather data and crop simulation models.
- Smartphones used for plant disease diagnosis or nutrient management decision-making (e.g., NM Rice www.irri.org/nmrice).
- Video technology and monitoring platforms for farmer-to-farmer extension, e.g., Digital Green (www.digitalgreen.org).
- Commodity exchanges accessible by mobile phones that give farmers access to markets and secure higher prices while processors benefit from high quality raw materials based on transparent grades and standards and easier aggregation of primary products.
- Mobile phone enabled portals and services for extension professionals, farmers, and agribusinesses, including credit, inputs, weather-indexed insurance, location-specific extension alerts and technical support, market prices and short-term weather forecasts.
- Tracking of government performance in providing an enabling environment for SAI, including seed delivery, extension services, local businesses and service providers for operations such as land preparation, planting, and application of pesticides.
- Digital applications for local value chain tracking and diagnostics to inform businesses, governments, and consumers, increase value chain efficiencies, and track food safety and losses.
- New bioinformatics platforms for speeding up gene discovery and breeding, especially for integrating complex traits into crops and livestock species important to smallholder farmers.
- Knowledge repositories and exchange platforms that enable development partners to distill and access context-specific learning to increase the effectiveness of development efforts.

- Mobile platforms that provide integrated agriculture, health, financial and education services to rural families, e.g., the MOTECH platform.

Promoting integrated landscape management
Main contributions: most Targets

To address the challenges of food insecurity, persistent poverty, climate change, ecosystem degradation and biodiversity loss successfully, it is critical to move beyond zero-sum strategies that solve one problem but exacerbate others. "Integrated landscape management" aims to realize synergies and reduce trade-offs among these multiple objectives. Farmers and land managers around the world are reaching out across traditional sectoral boundaries to forge partnerships with conservation organizations, local governments, businesses and others to solve problems that are inter-connected. More than 107 such initiatives have been documented in Latin America, over 85 in Africa and an Asian inventory is underway[210,211]. However, current institutions—still sectorally siloed—provide weak support for these efforts. In Lari-Kijabe in Kenya, smallholder farmer organizations are partnering with local governments, banks and conservation groups to expand agricultural markets and protect high-conservation value forests and watersheds. In the Maasai Steppeland of Tanzania, commercial avocado producers, pastoralists and conservation organizations are partnering to raise incomes and food security, while protecting wildlife. In Tigray, Ethiopia, restoration of highly degraded watersheds by community-government-NGO partnerships have enabled irrigation and water access, increased food production, and greatly reduced the need for food aid during droughts.

In 2012, a global coalition of more than 50 agriculture, environment and development organizations came together to implement the Landscapes for People, Food and Nature Initiative (www.landscapes.ecoagriculture.org). The Initiative is advancing viable pathways for sustainable development in places where food production, ecosystem health and human wellbeing must be achieved simultaneously. The top priority is to strengthen the capacity of existing landscape initiatives and mobilize cross-site learning, coordinated investment and documentation. To accelerate the scaling up of integrated landscape approaches, the Initiative is assisting countries to put in place supportive policy frameworks, encouraging businesses to pursue sustainable sourcing through landscape partnerships, expanding financing for integrated landscape investments and promoting science and knowledge systems for landscape solutions.

Transforming China's agriculture
Main contributions: Targets 5c, 6a, 6b, 6c, 8b, 9a, 9c

China produces the bulk of its food on millions of tiny farms, but hundreds of millions of people have already left the countryside in recent decades. China also imports huge amounts of agricultural products from other regions. Success in transforming the global food system will also depend on whether China can transform its agriculture. The sheer size of its population and food consumption, and the rapid pace of its economic development have already strained land, water, and other resources, leading to widespread environmental problems and food safety concerns. SAI will have to become the cornerstone for future food security and rural development in China. Perhaps the biggest challenge for China is to find "double high" SAI solutions that ensure high yields with high resource use efficiency, and also meet higher environmental protection and land quality standards. Being the world's largest fertilizer consumer, more effective nutrient management is of particular significance for China because current application rates of nutrients such as nitrogen and phosphorus are high, whereas their use efficiencies are often very low. Solving this problem requires better congruence between crop nutrient demand and nutrient supply from soil, fertilizer and other sources. The technologies and diagnostic tools needed have been developed by Chinese researchers, demonstrating that large gains in yields, income, water and nutrient use efficiency could be achieved[182,212,213216]. Adoption of such approaches could also lead to substantial reductions in GHG emissions. Nitrogen fertilizer-related emissions constitute about 7% of GHG emissions from the entire Chinese economy. Mitigation opportunities include improving methane recovery during coal mining, enhancing energy efficiency in fertilizer manufacture, and increasing the efficiency of N fertilizer use at the field-level. This could cut N fertilizer-related emissions by 20–63%, which would decrease China's total GHG emissions by 2–6%[43].

The main challenge is how to upscale knowledge-intensive management practices through suitable policies and extension models for different types of farming in China[212]. In small households with 0.5 ha land, "double high" agriculture requires organizing small farms into somewhat larger land units and working closely with farmers through village-based agricultural experts. This should also be tied into new business models for farming in China, such as small to medium agribusinesses, cooperatives and contract farming[208,214]. In contrast, large farms are found in Northeast China, with each household managing 25 ha or more land with modern machinery and good access to professional extension experts. In this case, even information technology-based management and large-scale agricultural service models have been tested and successfully adopted by these large-scale farms. Agricultural technology extension in China predominantly relies on public sector activities, with only a small, complementary role for the private sector. With further development of the Chinese economy the role of the private sector in research and extension of agriculture technology is becoming more important. Based on the characteristics of the main bodies involved in China, the approaches for agricultural technology transfer and extension for high-yield and high-efficiency crop production can include: (1) farm-based approaches for promoting knowledge transfer to farmers; (2) enterprise-based approaches for incorporating knowledge into commercial products; and (3) government-based approaches for improving the national extension network[212].

Monitoring the world's agricultural systems

Main contributions: all Targets

Effective monitoring networks are essential to track, anticipate and manage changes in the biophysical, economic, and social aspects of different farming systems around the world[143,167]. A global agricultural monitoring system should be established as a well-designed and well-directed network of partners engaged in collecting high-quality data required by a wide range of stakeholders. It would provide up to date information on the status of agriculture and progress towards meeting the agreed future SDG Targets, including environmental targets affected by agriculture. Simultaneously measuring indicators across SDGs - including many of those proposed in Chapter 3 - in an integrated monitoring system will allow scientists, land managers and other decision makers alike to find solutions to the most pressing problems facing global food security. It would help direct public and private investments, and would allow for quantification of the multifunctional aspects of agriculture and food systems in a comparable manner across scales.

Such a monitoring system would build on existing but often disconnected monitoring efforts. It would supplement and improve existing national and global statistics with high quality data collected at farm, landscape and regional scales. Both universal and site-specific metrics are needed to detect change over time and across scales[167]. This would include, for example, more precise data such as crop and livestock yields, weather data so that yields can be adjusted for climate variability, yield gaps based on simulation of yield potential and measurement of actual yields, nutrient application rates, budgets and efficiencies, crop losses by pests and diseases, water use and efficiency, measures of soil quality and ecological resilience, availability of credit and machinery, household income, and low-cost genetic fingerprinting to assess the diversity of the main crop varieties and animal breeds. It would utilize adaptive monitoring and hierarchical design strategies to address specific and new questions or hypotheses, including those that are subject to much public debate, such as the impacts of GM crops or tradeoffs of organic agriculture. Universities and International Agricultural Research Centers (the CGIAR and others), could play a major role in such an effort because they have thousands of experts in various disciplines and thousands of partners on the ground. An interdisciplinary monitoring network would also provide unique, exciting opportunities for students and others to learn about the science and practice of sustainable agriculture. The monitoring work would have to tie in with national statistical agencies, UN agencies and others who collect and analyze data on agriculture and associated and natural ecosystems, to overcome many of the current weaknesses in data coverage and quality (see Chapter 5.2). International donors should allocate sufficient amounts of long-term funding to support such an effort, which would benefit them and countries in making better decisions and tracking returns on investments.

4.3. Investing in long-term change

Foresight is needed to avoid running into another food crisis 20 or 30 years from now. In addition to investing in early solutions or technologies that are likely to become available in the next 5 to 10 years, strategic investments are needed to sustain and even accelerate the rate of progress over time. This requires large, stable investments in two major areas: (1) agricultural research with potentially high payoffs and (2) strengthening the capacity of National Agricultural Research Systems (NARS), including human resources development at all levels, from science to extension[215,216].

For some 10,000 years farming made progress through observation, tinkering and trial and error. Organized agricultural research has only been conducted for about 200 years. Its success has been spectacular, leading to a steady accumulation of knowledge as well as massive breakthroughs in the performance of agriculture. It has been demonstrated numerous times that rates of return on investment in agricultural R&D are high in both developed and developing countries[z], that spillover of innovations among countries is substantial, and that investments in R&D often have large, long-lasting cross-sectoral growth benefits[4,215,217-219]. It has also been shown that countries that have heavily invested in R&D, extension, and measures that favor long-term business and infrastructure development for commercialization of new knowledge and technologies have also had the strongest productivity growth[5,220]. Further, investments in R&D can have significant impacts on productivity growth even in the absence of improvements in infrastructure or extension, whereas the reverse is usually not the case[5]. Despite this track record and a modest increase in funding in recent years, agricultural R&D expenditures remain far too low in most countries. In 2008/9, global public spending on agricultural R&D totaled about US$32-34 billion, split about evenly between high-income and low/middle-income countries[163,221]. Private sector investments add another US$15-20 billion, 90% of which is in high-income countries. Altogether agriculture and food only account for about 5% of total global science spending. Moreover, Brazil, China and India alone account for half of all agricultural R&D spending in the low/medium income category, whereas many low- and middle-income countries still have very limited R&D capacity. It has been estimated that nearly half of the world's agricultural science knowledge stock has been generated by just seven countries, with the USA, Japan, and China accounting for one third[221].

There is no plausible reason for why returns on investments in agricultural R&D could be lower in the future. Investments in public agricultural research should be doubled within the next 10 years[215] and they need to be of a long-term, strategic nature, not driven by short-term thinking and bureaucracy that

[z] Annualized rates of return vary by country and type of innovation, but often range from 20% to 80% in agricultural research in developing countries. Calculations of rates of return may sometimes be biased because failures may not be included in impact studies or because attribution to research is difficult to quantify for some technologies and policy interventions.

causes high transaction costs. Although private sector funding for agricultural R&D has risen substantially in recent years, questions must be raised as to whether it can really substitute for public R&D[222]. 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 a decline in basic research needed to create new technology opportunities for the private sector, as well as a decline in the 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, but with better R&D funding mechanisms that create more space for scientists to actually be able to do creative science.

Larger, more predictable and less restrictive support for R&D involves investing in strong pipelines of both basic and applied research. Both are interlinked and need to be funded in parallel. Many exciting new ideas have been proposed or are already being pursued by research groups worldwide, addressing fundamental questions in agricultural sciences[223,224]. Most of them require large, longer-term public and private sector investment and effective collaboration of scientists worldwide. Some examples for potential future breakthroughs are shown in Box 4-6.

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 goals. Huge human resource gaps persist in many developing countries, particularly in Sub-Saharan Africa, but with the exception of China and India also in most countries of Asia. 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' and businesses' needs, and bring them towards application. Robots, computers, the internet or smartphones cannot do this. They are helpful tools, but not the primary means for innovation and enacting behavior change in the complex world of agriculture. Public science education on food, agricultural and environmental issues needs to be strengthened all the way from primary education to college. Curricula should be upgraded to include the best available science of sustainable agricultural intensification in an exciting manner, thus encouraging young people to become part of the transformative changes needed by seeking a career in the agriculture and food sectors. A global classroom, a network of knowledge centers who become global, regional and national leaders in agricultural sustainability science and practice, should be formed to raise the profile of agricultural science, mobilize action, connect young people worldwide, and also educate business executives and political leaders.

National Agricultural Research Systems (NARS)[aa] are the backbone of agricultural development in a country, but many will require a complete overhaul and even whole new models in order to be able to fulfill their mandate. At present, many are too weak in terms of human capital, infrastructure, operational funding, incentives, management and governance to undertake the work that will be required[216]. In many countries, NARS still depend highly on donor funding, which also creates volatility risks for pursuing a long-term national agenda. While international donors should be encouraged to invest more in both international and national agricultural R&D systems, most low- to middle-income countries should also aim to spend at least 1% of their agricultural GDP to support public agricultural R&D in their country. At present, most developing countries spend only about 0.5% of agricultural GDP on R&D[163]. Modernization of NARS and greater financial support should be an integral component of comprehensive national agricultural development and investment strategies, following an integrated,

[aa] Here we focus primarily on public sector research. The term National Agricultural Research and Extension Systems (NARES) is often used to describe the entire system of research and extension organizations in a country.

inclusive approach that is country-owned. Many good suggestions have been made and various new models have already been tried in recent years for modernizing national agricultural research as well as extension systems[216,226].

Box 4-6. Blue-sky research that could lead to future transformative changes in agriculture and food systems

- Massive discovery of genes' functions by sequencing and phenotyping the world's collections of wild and domesticated crop and animal species, and using that know-how in conventional and biotechnology applications for accelerating next generation crop and animal breeding. The revolutions in biological sciences and information technology have put this exciting opportunity at our fingertips. Potential returns on such investments are huge and broad, including for 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. The metabolic components already exist in C3 rice plants. However, the anatomical and biochemical features of C4 plants must be understood and transferred to rice plants. This is currently being pursued by a group of scientists from the International Rice Research Institute (IRRI) and advanced institutions around the world in the international C4 Rice Consortium, who hope to construct a functioning C4 rice plant within the next 20 years[113].
- Genetic improvements to increase the nitrogen use efficiency in non-leguminous crops, including engineering a mechanism for fixing atmospheric N_2 into such crop species[225]. The three major cereals (rice, wheat, maize) account for about 50% of global nitrogen fertilizer consumption. A breakthrough in nitrogen use efficiency of such staple crops would help decouple rising food production from rising fertilizer consumption, and make farming more profitable.
- Cost-effective small-scale production of ammonia integrated with renewable energy generation to meet local fertilizer supply needs and "store" energy in fertilizer to buffer intermittent supplies of electrical energy[41].
- Smart fertilizer technologies and/or genetic improvements that could double the crop recovery efficiency of applied phosphorus fertilizer. Typically, only 20-25% of the P applied with fertilizer is recovered by the crop in the first growing season. Although it can be increased through better nutrient management and stewardship programs in low-performing areas, new technology could enable increasing short- and/or long-term phosphorus efficiency. This would be more profitable for farmers, and also reduce the risk of P losses.
- Next generation biofuels and other bioenergy solutions that are more energy efficient, use crop residues and biomass waste, and don't consume more agricultural land or natural ecosystems.
- Environment-independent, self-sustained skyfarming[118] or other forms of vertical urban agriculture and horticulture, 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.
- Innovative payment and (digital) monitoring schemes for environmental services that incentivize the implementation of high ecological and social standards at landscape scale.
- Food market system innovations that can incentivize species and landscape diversity in agriculture, e.g., whole new storage facilities and computerized delivery systems for diverse products.

Generally speaking, there is a need to (i) move from supply-driven to demand-driven agricultural innovation systems that focus on the right priorities, including active participation by key stakeholders, and (ii) simplify the increasing complexity, fragmentation and lack of coordination of agricultural R&D funding. New, visionary R&D funding models are needed that

- Are founded in strategic long-term thinking;
- Have a clear outcome-focus and reward quality science and proven impact;
- Enable public-private collaboration in R&D and extension to cover all areas sufficiently and make faster progress;
- Encourage open access to information, data and other intellectual properties;
- Create a viable market for R&D outputs and innovation services;
- Enhance cross-border learning, cooperation and technology spillover;
- Stimulate more private investments in R&D and direct it to areas of public interest, including attracting new investors such as venture capital and social impact investors;
- Systematically improve public R&D infrastructure; and
- Build human capital.

5. Planning and implementing action

Implementation of the new SDGs through targets, indicators, planning and investments should be scalable from local to global levels, and must also be measureable at all levels and scales. The pathways towards more sustainable agriculture and food systems will vary by country as well as within countries, but could follow some common principles (Box 5-1).

In every village there is a huge diversity of households, from relatively better off to abjectly poor. Each country and each locality must choose its own agricultural transformation paths, and prioritize concrete solutions for them. Market-driven economic and technological growth will not be sufficient to achieve the necessary, deep transformation of the global food system because it lacks the incentives to confront all of the challenges that need to be tackled. Good governance – supported by good metrics – needs to direct the transformation process. Not all goals of sustainable agriculture and food systems can be achieved immediately and simultaneously because the challenges and uncertainties are simply too large and complex. Perfect, quick solutions rarely exist. Multiple "actionable" changes are the basis for moving towards achieving a major goal. A risk minimization strategy also offers greater potential for ownership and building consensus that results in real change. Its goal is to find ways of moving forward rather than seeking ultimate solutions that do not address the diverse, pressing needs of different countries, which too often result in no action being taken[77]. It may also include drastic actions that may have to be taken in certain cases, such as policies and good governance mechanisms that slow down and halt the destruction of forests or natural wetlands, the depletion of water resources, and the conversion of fertile agricultural land into housing and industrial zones, or provide the necessary controls over food quality and safety.

Planning for success requires an implementation plan that provides a roadmap to realize strategic goals. While the high-level SDGs for the post-2015 era will galvanize the global community to work towards shared development goals, country-by-country as well as local implementation plans will be required to achieve the targets. National and local governments need to take the lead in developing and implementing their own sustainable development strategies and action plans at different levels, based on the proposed SAI principles and the four dimensions of sustainable development. Improved measurement of development outputs and outcomes has to be an integral part of this, but moving beyond high-level global goals will also require solid "business plans for development" that provide a roadmap for success. Countries and local stakeholders need to enter the sustainable development path in the right order by defining their priorities and assessing the feasibility of different options. Action planning needs to be goal-oriented and systematic. National and local governments should apply structured assessment and business planning methodologies to analyze how various solutions could contribute to meeting one or more specific targets, and what the cost of different options is. Researchers must play an important role in guiding this process. A structured assessment and backcasting approach typically includes five steps:

- Background analysis: data collection, past trends and future projections, possible scenarios
- Analyze data on problem relevance: define and characterize key problems/opportunities
- Assess different technology/policy solutions (assumptions, timeframes, effectiveness, cost, etc.)
- Estimate outcomes and effects at scale (direct and indirect effects)
- Modeling of large-scale impact on development goals/targets: direct and indirect sectoral and cross-sectoral benefits; cost vs. benefits

Interesting examples have recently been demonstrated for assessing technology paths for decarbonizing California's energy supply through such a backcasting approach[227], or for climate change adaptation planning in Ethiopia[228].

Box 5-1. Some guiding principles for implementing Sustainable Agricultural Intensification

- Governments and international agencies should make sustainable development of agriculture a priority and support it through larger and sustained investments.
- The domestic private sector, composed of millions of farmers and other local businesses, is by far the biggest investor in agriculture and must be at the center of agricultural development strategies and plans.
- Countries should weigh the costs, benefits and potential tradeoffs of specific steps to take, but within a generic framework that aims to achieve transformative changes.
- Countries need to constantly adjust their own policies to remove barriers, take advantage of new technologies and create incentives for farmers, technology developers and the investment community to develop workable options for deploying into agricultural systems.
- Agricultural productivity growth in cereals and other staple food crops cannot be compromised because it is essential for eradicating poverty and hunger.
- Improvement of agriculture and food systems is a continuous, iterative process involving many public, civil society and private sector stakeholders. Many small steps must be taken, involving learning as well as requiring behavior change by all actors involved. Multi-faceted approaches are needed to respond to the diversity of farmers' environments, objectives, constraints and incentives and to ensure proper targeting.
- Thinking, policies and technologies from developed countries cannot be simply transferred to developing and transition countries to dictate what is right or wrong, but all opportunities for North-South as well as South-South sharing and learning should be exploited.
- Specific attention must be paid to increasing the resilience of crop and livestock systems, adapting agriculture to climate change and climatic extremes, reducing the water intensity of crop production, better nutrient management, improved animal health, and halting the expansion of agriculture into natural ecosystems of ecological high value.
- Greater equity is needed in terms of access to inputs and markets throughout the world to help smallholders escape from poverty and resource depletion traps.
- Farming, and the broader rural agribusiness sector, must provide attractive social and economic development opportunities for people living in rural areas, particularly women and the hundreds of millions of young people who will soon be looking for jobs. Women are key drivers of change in agriculture. They need to be empowered along the whole value chain, from equal access to land to opportunities for small business development in the agriculture and food sector.
- Better support systems are needed on the ground to accelerate progress, including more professional extension systems, mobile phone technology, soil data, real-time weather data, reference research information, crop information, etc.
- Implementing SAI should include efforts to integrate agriculture with other sectors to have greater impact, particularly on health, natural resource management, disaster risk reduction, gender, education and energy.
- Multiple stakeholders must be encouraged to participate in the SAI process. Programs and policy measures should encourage business development, public-private partnerships, and other measures through which a variety of sectors can work together on the ground.
- The engagement of farmers, communities and consumers should increase.
- Biophysical, economic, social and environmental metrics need to be collected in a comprehensive, reliable manner to assess different policy and technology options, make the right choices, and evaluate the performance of agriculture over time. Countries should adopt open data policies.

Political will is needed to implement a more coordinated and business approach to development, including behavior change on the part of all participants. One of the major challenges is the alignment of many actors who play different roles in development to ensure strategies are translated into tangible outputs and outcomes to improve food security and nutrition for the rural and urban poor. One initiative which has shown some success is the development of 'Innovation Platforms' to foster linkages between the many players in a specific value chain. These 'Innovation Platforms' or 'Innovation Hubs' bring together the public and private sectors, research and development, and actors at different places in the value chain to contribute to local innovation and strengthened chains. Local and national governments are often overwhelmed by disparate programs operating within their borders, but such platforms can give a solid base from which to drive action which is well coordinated. The range of organizations to coordinate with includes:

- National governments and local authorities
- National agricultural research and extension systems
- Universities
- Civil society organizations (CSOs), including farmers associations
- Private companies and industry associations
- Sustainable agriculture platforms and roundtables
- UN organizations such as FAO, WFP, UNEP, UNDP, and OECD
- Global and regional political bodies and organizations
- Global, regional and national initiatives, e.g., CAADP, G8 Alliance for Food Security and Nutrition, AGRA, African Fertilizer and Agribusiness Partnership (AFAP), Global Partnership on Nutrient Management (GPNM), Global Dryland Alliance (GDLA), Scaling Up Nutrition (SUN), etc.
- Large business-led initiatives, platforms (e.g., SAI Platform www.saiplatform.org) and development corridors (e.g., WEF/New Vision for Agriculture)
- Donors, development banks and funds, private foundations, and social/impact investors
- International agricultural research centers, e.g., those forming the CGIAR and the Association of International Research and Development Centers for Agriculture (AIRCA)

While many of these stakeholders have common goals, there is relatively little coordination among them along a commodity value chain in most developing countries compared to developed economies. Often implementation measures to increase farm productivity and profitability is hampered by partners not knowing how individual initiatives stitch together to support a robust and safe food system. The diversity of uncoordinated projects operating within a given country leads to fragmented, unsustainable investments that seldom reach large scale. Key steps towards addressing this critical issue include:

- Comprehensive, national and sub-national agricultural development strategies and investment plans which follow an integrated, inclusive approach, are evidence-based, and are driven by the needs of smallholder farmers and local entrepreneurs to become successful in producing, processing and marketing nutritious, safe food in an efficient and equitable manner.
- Laws, policies and implementation offices that guide and coordinate the activities of multiple actors and ensure transparency and accountability of development partners for outputs in support of national development goals.
- Establishment of scalable systems that support stakeholder engagement, sharing of information and practices, measurement, sustainability goal setting, training, extension, etc. so that diverse stakeholders can focus their resources on making a meaningful difference.
- The use of modern tools (e.g., mobile phones, satellite imagery, geospatial databases) to foster linkages along value chains and stronger coordination and engagement with farmers to increase the adoption of ecological intensification practices.
- Scorecards that leverage digital technologies to provide more granular feedback to governments on their progress towards SDGs across sectors, including the contributions of multiple actors involved.

There is a need for partner mapping within each country to enable organizations within regions and along different commodity value chains to self-assemble and make strategic contributions to increase value chain efficiency, reduce duplication and provide farmer-preferred inputs and services while supporting equitable market opportunities for smallholder farmers and their families. Providing the tools, many digitally enabled, to support value chain coordination and efficiency gains in service of farm families will be vital for success. Mechanisms, indicators and scorecards should be created that incentivize organizations to take ownership and become more effective in reducing poverty and increasing agriculture productivity in a sustainable manner. One example of this is the development of seed roadmaps to ensure crop improvement programs are placing appropriate emphasis on the markets and traits important to farmers through participatory testing and then build out seed production and distribution plans in partnership with a wide range of local partners. This deliberate approach to variety development and seed production and distribution puts in place the targets needed to realize national seed requirements for farmer- and market-preferred crops.

Countries and international donors need to make strong investments in the public sector, but they should also enable more sustainable business investment by creating infrastructure, providing security, stopping corruption, protecting human rights, encouraging education, and more. This is one of the prerequisites for leveraging large private sector investments in smallholder farming and food systems in developing countries[229]. With these in place private investments will grow and public–private partnerships (PPP) could flourish as a mechanism for implementing concrete solutions in different farming situations and food chains. There is a growing desire on the part of governments, universities, international institutions, and civil society organizations (CSOs) to work with the private sector, and vice versa. Experience so far shows that PPPs are easy to talk about but often hard to make work[230]. Nevertheless, some good examples have already emerged in recent years which have demonstrated success or promise at different scales such as smallholder input and service delivery systems, product supply chains, R&D, and large-scale investment corridors (Box 5-2). The latter, while offering potential solutions, should be developed in close consultation with local stakeholders, particularly the current land users.

There is also a need for alternative funding approaches that complement the traditional funding of R&D. "Pull mechanisms" are results-based financial incentives that reward successful innovations and their adoption, to overcome market failure and stimulate more private sector engagement in R&D[231,232]. AgResults, launched by the G20 in 2010, is a new global initiative to enhance smallholder welfare and improve food security for the poor and vulnerable through the use of "pull mechanisms" in agriculture.

Moving agriculture towards more sustainable productivity will require policy coherence and innovation (Box 5-3). These must often be coordinated within and across countries to achieve transformative change. Needed policy reforms include those that increase support for the rural sector by improving infrastructure, strengthening capacities along value chain actors, and stimulating innovation. Economies that are heavily dependent on agriculture sometimes tend to tax their rural sectors in favor of urban and industrial sectors. However, policies that support agriculture as well as rural infrastructure and enterprise will benefit the majority of the population, including the urban sector. A comparison with experiences from middle-income countries in Southeast Asia reveals, for example, that (i) the historical roots of economic success lie in pro-poor agricultural and rural development policies; (ii) even when it has been pro-rural, African development strategy has often not necessarily been pro-poor; and (iii) pro-poor agricultural development, not export-oriented industrialization, should be the first priority of African states seeking to achieve sustained growth and poverty reduction[233]. A key policy objective will be the support of capacity strengthening for the various stakeholder groups that are important for rural development. This includes farmers (with youth and women requiring particular attention), extension

Box 5-2. Examples of public-private partnerships and business initiatives in agriculture and food systems

Unilever, Kenyan Tea Development Agency and the UK Government

The objective of this pilot is to seek out new methods for encouraging Kenyan smallholders to adopt sustainable farming practices. Costs are shared between the UK government (DFID, 45%), Unilever (35%), the Kenyan Government (18%) and Wageningen University and Research Centre (WUR, ~2%). Results obtained so far have shown yield improvements of between 5-15% and improved farmer incomes. This is now being rolled out by the Kenyan Tea Development Agency to 500,000 farmers. Eco-certification is a key element in this partnership.

Hybrid Rice Development Consortium (HRDC)

Small, medium and large seed companies engaged in hybrid rice breeding and commercialization need to have access to traits, breeding materials, breeding support and other information generated by public sector research. The Hybrid Rice Development Consortium (HRDC) was established by the International Rice Research Institute (IRRI) in 2008 as a PPP model to advance hybrid rice development. It currently has 34 private businesses and 34 public-sector institutions as members. Members of the HRDC provide feedback on hybrid rice research priorities. Private sector members provide financial support through annual membership and germplasm fees and in return gain access to diverse germplasm and other benefits, including training. HRDC members can also seek bilateral collaboration with IRRI and other public sector partners. This mechanism has allowed IRRI to increase its hybrid rice breeding capacity in a demand-driven, self-sustained manner. Within four years it has led to a 10-fold increase in the volume of germplasm shared with both private and public members of the HRDC. http://hrdc.irri.org

Sustainable Agriculture Initiative Platform

Food industries are the biggest purchasers of agricultural raw materials. In order to rely on a constant, increasing and safe supply of agricultural raw materials, these must be grown in a sustainable manner. The SAI Platform is a food industry organization to support the development of sustainable agriculture. The SAI Platform today counts over 50 members. It aims at developing sustainable agriculture for mainstream agricultural produce through a continuous improvement process that allows for more flexible adoption by farmers worldwide. Examples of recent activities include principles and practices for sustainable water management at farm level, recommendations for sustainability performance assessment, a standardized methodology for the dairy sector to assess greenhouse gas emissions, and executive training on sustainable sourcing. www.saiplatformaust.org

Grow Africa

Grow Africa is a partnership platform that seeks to accelerate private-sector investment in African agriculture by supporting partner countries in developing investment blueprints, building a pipeline of investments, and strengthening cross-sector collaboration. It provides support for innovative finance, risk management and partnership building, with the intent of boosting smallholders and agricultural enterprises by tackling constraints to their commercial viability. Grow Africa is based on national agricultural priorities in support of the Comprehensive African Agricultural Development Program (CAADP), with the World Economic Forum (WEF) as a major convening partner. Goals for specific initiatives are defined by a country's comparative advantages and accessible market opportunities. Current initiatives focus on agricultural growth corridors in Burkina Faso, Ethiopia, Ghana, Kenya, Mozambique, Rwanda and Tanzania. Partners include the governments of these countries, international donors, development organizations and private companies. http://growafrica.com services (including non-governmental groups), as well as enterprises that provide services and support value chains, such as those involved in finance, input supply, transportation, drying, milling, and marketing. Government policies on agricultural inputs such as seeds, fertilizers, pesticides and machinery are of particular importance for agriculture, but they sometimes provide wrong incentives or result in barriers that slow down progress. Well-targeted fertilizer subsidies play a major role in increasing productivity and halting soil nutrient depletion, particularly in Sub-Saharan Africa, but fertilizer subsidies can also lead to excessive or imbalanced use, or become a major economic burden for a country if they become permanent, large entitlements that do not encourage adoption of better management practices. Machines are often handed out for free or at highly subsidized prices, but without an agribusiness sector that provides the necessary training and service many break down quickly and end up in machine graveyards that can be found in many developing countries. This contrasts with a very different, successful model - the small machines revolution (engines, pumps, hand tractors, tillers) that powered the Green Revolution in Asia, which was largely driven by local entrepreneurs[234]. Could this be a suitable model for Africa? What policies could enable it? Generally speaking, input subsidies or credit schemes should become market-smart and target smallholders and small entrepreneurs, e.g., through vouchers, grants, or loans to promote private sector solutions; they should be temporary, not permanent; and they should be contract-based, with mechanisms that ensure that contracts are being honored by everyone in the chain.

Intellectual property rights (IPR), regulations for acquiring, sharing, import and export of germplasm, variety release systems, seed laws, seed subsidies and other seed-related policies to a large extent influence progress in breeding, the development of a vibrant seed industry with numerous local businesses, and affordable access to new varieties by farmers. This is a rapidly changing area in which countries constantly need to adjust their policies to address emerging technology opportunities. Barriers to innovation that slow down the time to market or increase the cost of getting a new product to market to a level that is only affordable by few companies with sufficient resources need to be removed[235]. For the majority of crops it typically takes 12-15 years to breed, test, release and disseminate seed of a new variety to farmers. This slow process is one of the reasons why many farmers cannot take advantage of better varieties. The time from a cross made to quality seed in the hands of a farmer can be cut in half through modern breeding technologies and the right government policies and support mechanisms for speeding up release and seed commercialization through public and private channels. In India maize and pearl millet yields grew significantly during the last two decades due partly to a combination of public policies that encouraged private investment in India's seed industry and intellectual property rights conferred by hybridization that addressed both the private sector's need for ownership as well as the nation's need for productivity growth[236].

Governments should design and implement national policies that are modeled after the *Voluntary guidelines on the responsible governance of tenure of land, fisheries and forests in the context of national food security*[151]. In many countries this may require placing constraints on the conversion of natural ecosystems to agriculture or policies that minimize the loss of productive agricultural land to industrialization and urbanization. Economic instruments should be used for sustainable land management, water resource management (e.g., water pricing) and ecosystem restoration. Science-based fisheries policy and governance reforms are needed to promote a complementary role of sustainable capture fisheries and aquaculture, and safeguard the diversity of global fish stocks[51].

Information and communications technologies (ICTs) have much to offer for enhancing planning and implementation of agricultural transformation processes. While ICTs cannot replace interpersonal interactions, digital communications can certainly enhance information exchange and provide the analytical power needed for planning, decision-making, real-time feedback and other forms of evaluation. Besides the possibility of inexpensive provision of information to populations who are otherwise relatively isolated, ICTs have the potential to foster exchange of information among households and communities, as well as crowd-sourcing of data and opinions.

Box 5-3. The enabling role of agricultural policies

New technologies are important, but policy and institutional reforms will be needed to align producer and consumer incentives and thus implement transformative changes in agriculture and food systems. The general principles (Chapter 2), goals, and targets for sustainable development (Chapter 3) as well as the available solutions for SAI (Chapter 4) provide overall guidance for priority setting and choosing policy options. Transparency, inclusiveness, good monitoring, critical review and dynamic adaptation of policies to specific, changing contexts will determine whether the stated targets can be met. Development of policies is by nature politically driven, based on the specific challenges faced in each country. Agricultural policies should support systems-based approaches to improving sustainability performance on site-specific levels across nations and regions. They must be developed with extensive stakeholder engagement to ensure that diverse perspectives are considered and included. The outcomes of these policies must be monitored well through suitable indicators, some of which could be internationally agreed and others nationally defined[129]. Countries, through their policies, should aim to incentivize action by all actors towards more sustainable agricultural production and food consumption practices. They should stimulate - not distort - the development of a vibrant, competitive agribusiness sector that serves the needs of farmers and consumers. Critical areas to improve include policies on agricultural trade and market access, prices, financing, food processing and safety, consumer behavior, agricultural inputs and subsidies, land tenure, water rights and use, access to knowledge and technology, rural infrastructure and labor, agricultural research and extension systems, protection of ecosystems, and use of ecosystem services as well as gender roles, rural education and health. Many will require substantial institutional reforms in many countries. Countries in which the poorest households spend a large share of their income on food need to pay special attention to the stability of food prices, and establish the necessary safety nets and social protection mechanisms. Regulation or protection are an important part of good policy setting and governance, but such tools should be used with care, focusing on specific areas such as protecting the poor, ensuring food safety, or protecting vulnerable natural assets, particularly forests, water and fish stocks. Countries should also aim to share their experiences and align critical policies to overcome present barriers for technology development and adoption and thus make faster progress in meeting their own targets. Actual implementation of policies must be monitored rigorously, and due attention should be given to policy research to establish causality between specific policy initiatives and progress toward policy goals.

6. Concluding remarks

The unique opportunity to eradicate poverty and hunger in our generation and make agriculture and food systems more sustainable should not be missed. The primary objective of agriculture - which cannot be compromised - is to produce enough food to sustainably feed 9 or 10 billion people by 2050. This largely needs to be accomplished by crop and animal productivity increases, reducing food losses and waste, and changing diets, always keeping in mind that the Earth's natural resource base is finite. In addition to the already common pressures of the past, our generation is facing new challenges: How to make sure that we do not run out of water? How to preserve or improve soils? How to adapt to climatic extremes? Is the best future for many smallholder farmers to get out of farming? How do we create better jobs and higher incomes for them in rural or urban areas? How do we ensure healthier diets and lifestyles in all countries?

We live in an ever-changing world in terms of population, resource demands and constraints, climate, and even political volatility. Meeting future food demand will require shifts in behavior as well as shifts towards more sophisticated technologies, information and knowledge management systems for farming systems and whole value chains, but also policy-making, and market and incentive systems for investment in ecosystem services.

We need to be realistic about the future of smallholder farming in developing countries. For many small farming households exiting the agricultural sector may be the best strategy to overcome current poverty traps caused by resource constraints that also restrict the adoption of better technologies. Access to better education and jobs may offer future generations a chance for a different perspective on life, while those who remain in farming may have a greater chance to consolidate land holdings and thus modernize many operations for greater income potential.

The 2015 to 2030 period must become a period of serious transition towards food systems that operate based on SAI principles. It is possible to effectively end extreme poverty and hunger during this period, but it will probably take longer to completely halt and reverse all of the negative environmental and health impacts of contemporary food systems. However, if political will, governance and human behavior can change as rapidly as science and technology emerge, policy coherence for development, sustainable agriculture and food systems can become the new global standard, not the exception. Prosperous, healthy and resilient rural communities will be needed to produce the world's future food in a sustainable manner.

Concerted, coordinated action is needed, with increased, sustained investment in agriculture and rural development. We need to make farming more precise and more attractive to systematically improve sustainability performance using new technology. We need new implementation models that can unlock the real potential of the public and private sectors in addressing complex problems, including monitoring, learning, and prudently adapting. Markets alone are not enough; the private sector will also have to change its business models, and good governance will be essential, including more restraint in exploiting critical resources such as land, water, and forests.

Aspirations of *maximum consumption* should be replaced by patterns of *optimized consumption*. The available technical solutions are well advanced, but we also need to overcome systemic political, economic and social barriers to change, which are substantial. Strong multi-sectoral cooperation will be needed to address the development challenges facing humanity and the planet.

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Annex 1. A baseline scenario for future production of cereals and meat

Region	Cereals production (Million metric tons)			Meat production (Million metric tons)		
	2010	**2030**	**2050**	**2010**	**2030**	**2050**
East Asia and Pacific	519.6	640.0	708.6	102.2	125.1	138.7
Europe and Central Asia	277.7	374.7	467.0	19.5	25.5	29.4
Latin America and the Caribbean	156.1	240.2	313.8	41.6	62.5	80.2
Middle East and North Africa	68.9	102.0	126.7	6.2	11.4	17.8
South Asia	291.8	363.1	392.3	9.5	20.0	35.2
Sub-Saharan Africa	95.9	158.4	225.3	8.5	16.2	25.7
Developed	711.0	898.6	985.8	91.2	114.0	129.2
Developing	1410.2	1879.7	2234.1	188.0	261.4	327.8
World	**2121.2**	**2778.4**	**3219.9**	**279.2**	**375.4**	**457.0**

Source: M. Rosegrant, IFPRI, IMPACT model predictions, adapted[65]. IMPACT covers 46 crops and livestock commodities and 115 countries/regions linked through international trade and 281 food production units. Demand is a function of prices, income, and population growth. Crop production is determined by crop and input prices, the rate of productivity growth, and water availability. The underlying data and model used make many assumptions about the future trajectories of food demand and supply. Uncertainties associated with such projections are generally large and so are differences among countries and regions.

This Business-As-Usual scenario assumes a continuation of current trends and food consumption, agricultural policies and investments in agricultural productivity growth. Population growth is the "median" variant of the UN projections (esa.un.org/wpp). Real prices for major agricultural commodities continue to rise due to increasing demand (population growth and per capita consumption), increasing agricultural land prices, and land and water constraints to expanding production. Meat consumption accelerates in developing countries, but also continues to increase in developed countries. Global per capita consumption of meat would rise from 40.2 kg in 2010 to 44.8 kg in 2030 and 48.8 kg in 2050. Total meat production would grow by 34% in 2030 relative to 2010, and by 64% in 2050. Global per capita consumption of cereals would rise from 150 kg in 2010 to 151.6 kg in 2030 and 153.4 kg in 2050. Cereals production would grow by 31% in 2030 (relative to 2010) and by 52% in 2050. World harvested crop area would increase, putting additional pressure on natural resources. Use of fertilizers and other inputs would continue to rise at current rates. Productivity and efficiency gains would be too small to significantly reduce the negative environmental impacts of agriculture. It would also be difficult to eradicate poverty and food insecurity. The number of people at risk of hunger would only decline by around 20%, from 918 million in 2010 to 749 million in 2050. The number of malnourished children would only decline by about 30%, from 164 million to 117 million.

This scenario illustrates some of the key principles and interactions involved in addressing multiple development goals through changes in agriculture and food systems. Productivity increases play a key role in achieving the targets of future, sustainable agriculture. However, to eradicate poverty, hunger, and other forms of malnutrition by 2030, crop and animal productivity growth rates would need to be higher than in the BAU scenario. Furthermore, achieving all of the targets of sustainable agriculture and food systems, including better environmental stewardship, protection of natural resources, and healthier human beings, requires deeper, transformative changes in how the world consumes and produces food. It can probably not be achieved through productivity and efficiency increases alone.

Annex 2. Sustainable Development Goals and Targets proposed by the Sustainable Development Solutions Network.

Goals and Targets are for 2030 unless otherwise noted. Targets marked with (*) need to be specified at country or sub-national level. Each target will require one or more indicators to be developed at a later stage.

PREAMBLE[bb]

The Sustainable Development Goals (SDGs) build on the success of the Millennium Development Goals (MDGs) and aim to finish the job of ending extreme poverty in all its forms. The SDGs reaffirm the need to achieve sustainable development by promoting economic development, social inclusion, environmental sustainability, and good governance including peace and security. These goals reaffirm human rights and underscore the right to development as central objectives. They are universal and apply to all countries, national and local governments, businesses, and civil society. Sustainable development will require that the goals be pursued in combination, rather than individually or one at a time.

GOAL 1: END EXTREME POVERTY INCLUDING HUNGER[cc]

End extreme poverty in all its forms (MDGs 1-7), including hunger, child stunting, malnutrition, and food insecurity. Support highly vulnerable countries.

Target 1a. End absolute income poverty ($1.25 or less per day) and hunger, including achieving food security and appropriate nutrition, and ending child stunting (MDG 1).

Target 1b. [Other suitably revised targets of MDGs 2-7 included here or below.]

Target 1c. Provide enhanced support for highly vulnerable states and Least Developed Countries, to address the structural challenges facing those countries, including violence and conflict.*

GOAL 2: ACHIEVE DEVELOPMENT WITHIN PLANETARY BOUNDARIES

All countries have a right to development that respects planetary boundaries, ensures sustainable production and consumption patterns, and helps to stabilize the global population by mid-century.

Target 2a. Each country reaches at least the next income level as defined by the World Bank.[dd]

Target 2b. Countries report on their contribution to planetary boundaries and incorporate them, together with other environmental and social indicators, into expanded GDP measures and national accounts.*

Target 2c. Rapid voluntary reduction of fertility through the realization of sexual and reproductive health rights in countries with total fertility rates above [3] children per woman and a

[bb] Preamble based on the Rio+20 outcome document.

[cc] The term hunger as used here embraces various things, including child stunting, food insecurity, and malnutrition. Appropriate indicators will need to be chosen to reflect the full spectrum of what constitutes hunger.

[dd] E.g. Low-Income Countries become at least Lower-Middle-Income Countries.

continuation of voluntary fertility reductions in countries where total fertility rates are above replacement level.*

GOAL 3: ENSURE EFFECTIVE LEARNING FOR ALL CHILDREN AND YOUTH FOR LIFE AND LIVELIHOOD

All girls and boys complete affordable and high-quality early childhood development programs, and primary and secondary education to prepare them for the challenges of modern life and decent livelihoods. All youth and adults have access to continuous lifelong learning to acquire functional literacy, numeracy, and skills to earn a living through decent employment or self-employment.

Target 3c. All girls and boys have equal access to quality early childhood development (ECD) programs.

Target 3d. All girls and boys receive quality primary and secondary education that focuses on learning outcomes and on reducing the dropout rate to zero.

Target 3e. Youth unemployment rate is below [10] percent.

GOAL 4: ACHIEVE GENDER EQUALITY, SOCIAL INCLUSION, AND HUMAN RIGHTS FOR ALL

Ensure gender equality, human rights, the rule of law, and universal access to public services. Reduce relative poverty and other inequalities that cause social exclusion. Prevent and eliminate violence and exploitation, especially for women and children.

Target 4b. Monitor and end discrimination and inequalities in public service delivery, the rule of law, access to justice, and participation in political and economic life on the basis of gender, ethnicity, religion, disability, national origin, and social or other status.

Target 4c. Reduce by half the proportion of households with incomes less than half of the national median income (relative poverty).

Target 4d. Prevent and eliminate violence against individuals, especially women and children.*

GOAL 5: ACHIEVE HEALTH AND WELLBEING AT ALL AGES

Achieve universal health coverage at every stage of life, with particular emphasis on primary health services, including reproductive health, to ensure that all people receive quality health services without suffering financial hardship. All countries promote policies to help individuals make healthy and sustainable decisions regarding diet, physical activity, and other individual or social dimensions of health.

Target 5a. Ensure universal access to primary healthcare that includes sexual and reproductive healthcare, family planning, routine immunizations, and the prevention and treatment of communicable and non-communicable diseases.[ee]

Target 5b. End preventable deaths by reducing child mortality to [20] or fewer deaths per 1000 births, maternal mortality to [40] or fewer deaths per 100,000 live births, and mortality under 70 years of age from non-communicable diseases by at least 30 percent compared with the level in 2015.[ff]

[ee] We recommend that countries retain suitably updated MDG indicators for HIV/AIDS, TB and malaria.

[ff] Countries that have achieved the mortality targets should set more ambitious aggregate targets that are commensurate with their development and ensure that the minimum quantitative targets are achieved for every sub-population.

Target 5c. Promote healthy diets and physical activity, discourage unhealthy behaviors, such as smoking and excessive alcohol intake, and track subjective wellbeing and social capital.*

GOAL 6: IMPROVE AGRICULTURE SYSTEMS AND RAISE RURAL PROSPERITY

Improve farming practices, rural infrastructure, and access to resources for food production to increase the productivity of agriculture, livestock, and fisheries, raise smallholder incomes, reduce environmental impacts, promote rural prosperity, and ensure resilience to climate change.

Target 6a. Ensure sustainable food production systems with high yields and high efficiency of water, soil nutrients, and energy, supporting nutritious diets with low food losses and waste.*

Target 6b. Halt forest and wetland conversion to agriculture, protect soil and land resources, and ensure that farming systems are resilient to climate change and disasters.*

Target 6c. Ensure universal access in rural areas to basic resources and infrastructure services (land, water, sanitation, modern energy, transport, mobile and broadband communication, agricultural inputs, and advisory services).

GOAL 7: EMPOWER INCLUSIVE, PRODUCTIVE, AND RESILIENT CITIES

Make all cities socially inclusive, economically productive, environmentally sustainable, secure, and resilient to climate change and other risks. Develop participatory, accountable, and effective city governance to support rapid and equitable urban transformation.

Target 7a. End extreme urban poverty, expand employment and productivity, and raise living standards, especially in slums.*

Target 7b. Ensure universal access to a secure and affordable built environment and basic urban services including housing; water, sanitation and waste management; low-carbon energy and transport; and mobile and broadband communication.

Target 7c. Ensure safe air and water quality for all, and integrate reductions in greenhouse gas emissions, efficient land and resource use, and climate and disaster resilience into investments and standards.*

GOAL 8: CURB HUMAN-INDUCED CLIMATE CHANGE AND ENSURE SUSTAINABLE ENERGY

Curb greenhouse gas emissions from energy, industry, agriculture, the built environment, and land-use change to ensure a peak of global CO_2 emissions by 2020 and to head off the rapidly growing dangers of climate change.[gg] Promote sustainable energy for all.

Target 8a. Decarbonize the energy system, ensure clean energy for all, and improve energy efficiency, with targets for 2020, 2030, and 2050.*

Target 8b. Reduce non-energy-related emissions of greenhouse gases through improved practices in agriculture, forestry, waste management, and industry.*

Target 8c. Adopt incentives, including pricing greenhouse gas emissions, to curb climate change and promote technology transfer to developing countries.*

[gg] The Fourth Assessment Report of the IPCC (2007) has defined this level as global average temperatures that are 2°C above the pre-industrial level. Recent scientific evidence suggests the need to reduce the long-term temperature increase to 1.5°C or less. The global emission reduction target should be regularly updated in view of the growing body of scientific evidence.

GOAL 9: SECURE ECOSYSTEM SERVICES AND BIODIVERSITY, AND ENSURE GOOD MANAGEMENT OF WATER AND OTHER NATURAL RESOURCES

Biodiversity, marine and terrestrial ecosystems of local, regional, and global significance are inventoried, managed, and monitored to ensure the continuation of resilient and adaptive life support systems and to support sustainable development.[hh] Water and other natural resources are managed sustainably and transparently to support inclusive economic and human development.

Target 9a. Ensure resilient and productive ecosystems by adopting policies and legislation that address drivers of ecosystem degradation, and requiring individuals, businesses and governments to pay the social cost of pollution and use of environmental services.*

Target 9b. Participate in and support regional and global arrangements to inventory, monitor, and protect biomes and environmental commons of regional and global significance and curb trans-boundary environmental harms, with robust systems in place no later than 2020.

Target 9c. All governments and businesses commit to the sustainable, integrated, and transparent management of water, agricultural land, forests, fisheries, mining, and hydrocarbon resources to support inclusive economic development and the achievement of all SDGs.*

GOAL 10: TRANSFORM GOVERNANCE FOR SUSTAINABLE DEVELOPMENT

The public sector, business, and other stakeholders commit to good governance, including transparency, accountability, access to information, participation, an end to tax and secrecy havens, and efforts to stamp out corruption. The international rules governing international finance, trade, corporate reporting, technology, and intellectual property are made consistent with achieving the SDGs. The financing of poverty reduction and global public goods including efforts to head off climate change are strengthened and based on a graduated set of global rights and responsibilities.

Target 10a. Governments (national and local) and business commit to the SDGs, transparent monitoring, and annual reports - including independent evaluation of integrated reporting for all major companies starting no later than 2020.*

Target 10b. Adequate domestic and international public finance for ending extreme poverty, providing global public goods, capacity building, and transferring technologies, including 0.7 percent of GNI in ODA for all high-income countries, and an additional $100 billion per year in official climate financing by 2020.

Target 10c. Rules for international trade, finance, taxation, business accounting, and intellectual property are reformed to be consistent with and support achieving the SDGs.

[hh] In line with the Aichi Biodiversity targets to be achieved by 2020.

Annex 3. Composite indices and tools for analysis, decision making and communication

Many composite indices and other decision or communication tools have been proposed in recent years to score multiple functions of agriculture and food systems. Generally speaking, many of them suffer from three basic shortcomings: (i) the quality of the underlying component data, (ii) scoring of qualitative data, and (ii) correlation and weighting of the various quantitative or qualitative component indicators. Nevertheless, composite indices have an important role to play in communicating to a broader audience the multiple dimensions of food security and sustainable agricultural development in user-friendly numbers, charts and tables. They are thus an integral part of decision-making and implementation strategies aimed at changing behavior and triggering more action at different levels. In general, composite indices, footprint tools or similar approaches should be (i) science-based; (ii) outcome- and action-oriented (iii) applicable at different scales, from the farm and value chain scale (where the change must happen) to the national scale (where progress towards meeting targets must be measured); (iv) capable of measuring trends over time, and (v) primarily based on credible, publicly available data. Preference should be given to tools that are based on well-defined, measurable components that can stand on their own and are also linked to key indicators for measuring progress towards achieving SDG targets (see Chapter 3.2.).

For illustration we provide six different examples:

The **Global Hunger Index (GHI)**[237] is designed to comprehensively measure and track hunger globally and by country and region. Calculated each year, the GHI aims to highlight successes and failures in hunger reduction, raise awareness and help understand regional and country differences in hunger to trigger further action. To reflect the multidimensional nature of hunger, the GHI combines three equally weighted indicators into one index number: Undernourishment: the proportion of undernourished as a percentage of the population; Child Underweight: the proportion of children under age of five who are underweight; and Child Mortality: the mortality rate of children under age of five. www.ifpri.org/book-8018/ourwork/researcharea/global-hunger-index

The **Global Food Security Index (GFSI)** considers four core issues of food security across 105 countries: affordability, availability, quality and safety. The index is a dynamic quantitative and qualitative scoring model, constructed from 25 unique indicators, that measures these drivers of food security across both developing and developed countries. It includes several unique qualitative indicators, many of which relate to government policy, to capture drivers of food security which are not currently measured in other international datasets. The GFSI is updated on a quarterly basis to adjust for the impact of fluctuating food prices. Its major goal is to assess in a timely manner which countries are most and least vulnerable to food insecurity. foodsecurityindex.eiu.com

The **Women's Empowerment in Agriculture Index (WEAI)** measures the empowerment, agency, and inclusion of women in the agriculture sector to identify ways to overcome those obstacles and constraints. It aims to increase understanding of the connections between women's empowerment, food security, and agricultural growth. It measures the roles and extent of women's engagement in the agriculture sector in five domains: (1) decisions about agricultural production, (2) access to and decision making power over productive resources, (3) control over use of income, (4) leadership in the community, and (5) time use. The five domains comprise ten indicators. Each domain is weighted equally, as are each of the indicators within a domain. The WEAI identifies women who are disempowered and tries to understand how autonomy and decision-making can be increased. The WEAI is also a useful tool for tracking progress toward gender equality, which is one of the current Millennium Development Goals. www.ifpri.org/publication/womens-empowerment-agriculture-index

National Water Security Index (NWSI)[238] The Asian Water Development Outlook measures the overall national water security as the composite result of five interdependent dimensions, because a single focus on any of these is insufficient to guide decisions or assess outcomes in the water sector. The five dimensions are (1) Household water security, (2) Economic water security, (3) Urban water security, (4) Environmental water security, and (5) Resilience to water-related disasters. Each of the five dimensions is measured on a scale of 1-5 (1 = Hazardous, 5 = Exemplary) using 3-4 sub-indices (indicators) for each dimension. The NWSI is calculated as the populated-weighted average of the five key dimensions of water security, and further aggregated up to sub-regions. Countries and regions with a low overall NWSI are described as hot spots, where additional efforts and targeted investments are required. The NWSI can be used to track progress at country and regional scale towards improving water security as a whole and for its various components. www.adb.org/publications/asian-water-development-outlook-2013

The **Rice Bowl Index (RBI)** is a public-private sector initiative that aims to provide a platform for joint action between various governmental and non-governmental stakeholders. The tool serves as a common language for different stakeholders to engage in purposeful dialogue leading to solutions-oriented action. The RBI consists of a quantitative and a qualitative component, which are currently measured for 14 countries in the Asia-Pacific region. The quantitative component is a modular diagnostic platform examining the key enablers and disablers of food security. The RBI defines these as Demand & Price; Environmental Factors; Farm-level Factors; and Policy and Trade. Each driver is a composite of 4-9 different metrics and proxies which are measured by using publicly available data, such as consumer price index, cereal yield, arable land, food consumption, infrastructure, and water availability. The qualitative component is a white paper (and an update is published every 6 months) which interprets the platform data and identifies areas which require increased attention in terms of the development of appropriate policy solutions, investment in technology and infrastructure, and the creation of economic opportunities for farmers and the communities in which they live and work.
www.ricebowlindex.com

Field to Market is an alliance of nearly fifty organizations including producer organizations, agribusinesses, food companies, conservation organizations and other not-for-profit organizations, universities, and agency partners in the USA. It aims to create opportunities across the agricultural supply chain for continuous improvements in productivity, environmental quality, and human well-being. A national report is published every four years (last report: 2012) to assess environmental and socioeconomic indicators for measuring outcomes of on-farm agricultural production in the United States. The report analyzes trends over time in major agricultural crops at the national scale. Its first part analyzes five environmental indicators (land use, soil erosion, irrigation water applied, energy use, and greenhouse gas emissions), each of which is presented in three formats: resource use/impact per unit of production, resource use/impact per acre, and total resource use/impact. For ease of communication, trends are shown in spider diagrams for 5-year periods, with 2000 as reference year. In a second part, six socioeconomic indicators (debt/asset ratio, returns above variable costs, crop production contribution to national and state gross domestic product, non-fatality injury, fatality, and labor hours) are assessed. Moreover, a Fieldprint Calculator is available online as an educational tool designed to help farmers assess how their own operational decisions affect overall sustainability performance. The calculator is an easy way to find out how a farmer's current land use, energy use, water use, greenhouse gas emissions, and soil loss compare with state and national averages.
www.fieldtomarket.org

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