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The role of science, technology and innovation in ensuring food security by 2030

Report of the Secretary-General

Executive summary

This report identifies, analyses and presents for discussion key issues concerning the role of science, technology and innovation (STI) in ensuring food security by 2030, particularly in developing countries. The report also highlights contributions by Member States on good practices and lessons for applying STI for food security. Chapter I provides an introduction to the global challenge of food security. Chapter II presents technologies that can play a role in addressing the dimensions of food security, namely food availability, access, utilization and use, and stability. Chapter III highlights how policymakers can build and strengthen innovative food systems to appropriately harness science and technology for food security. Chapter IV presents findings and suggestions for consideration by Member States and other relevant stakeholders.

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Introduction

1. At its nineteenth session, held in Geneva, Switzerland in May 2016, the Commission on Science and Technology for Development selected "The role of science, technology and innovation in ensuring food security by 2030" as one of its two priority themes for the 2016–2017 intersessional period.

2. To contribute to a better understanding of this priority theme and to assist the Commission in its deliberations at its twentieth session, the secretariat of the Commission convened a panel meeting in Geneva from 23 to 25 January 2017. This report is based on the findings of the intersessional panel, including the group discussions held within the framework of the panel, national reports contributed by members of the Commission and inputs from experts in different regions.

I. The challenge of food security

3. Food security is usually framed in four dimensions: food availability, access to food, food utilization and use, and food stability. These dimensions build the overall framework of the definition established by the Food and Agriculture Organization of the United Nations (FAO): "Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life".[1]

4. About 795 million people, or every ninth person, is undernourished, including 90 million children under the age of five. The vast majority of them (780 million people) live in the developing regions, notably in Africa and Asia. Depending on the region considered, the share of undernourished people differs considerably, ranging from less than 5 per cent to more than 35 per cent. In particular, sub-Saharan Africa shows high values, with almost 25 per cent of the population undernourished. While the hunger rate – the share of undernourished in the total population – has fallen in the region, the number of undernourished people has increased by 44 million since 1990 due to population growth. In absolute terms, the number of people exposed to food insecurity is highest in South Asia, with 281 million undernourished people.[2]

5. Across all countries, people living in rural areas are the most exposed to food insecurity, owing to limited access to food and financial resources.[3] Among them, 50 per cent are smallholder farmers. In Asia and sub-Saharan Africa, these farms produce more than 80 per cent of the food; 84 per cent of family farms are smaller than 2 hectares, and family farmers manage only 12 per cent of all agricultural land.[4]

6. Sustainable Development Goal 2 aims to end hunger and ensure access to sufficient, safe and nutritious food by all people all year round. Overall, most of the Sustainable Development Goal targets are related to the overarching issue of achieving food security on a global scale.

[1] FAO, 2016, Food security indicators, available at http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/ (accessed 2 September 2016).

[2] FAO, International Fund for Agricultural Development and World Food Programme, 2015, *The State of Food Insecurity in the World: Meeting the 2015 International Hunger Targets – Taking Stock of Uneven Progress* (FAO, Rome).

[3] Ibid.

[4] FAO, 2015, *The State of Agricultural Commodity Markets 2015–16: Trade and Food Security – Achieving a Better Balance between National Priorities and the Collective Good* (Rome).

7. Poverty and climate change exacerbate the global challenge of food insecurity. Other factors are directly implicated in the achievement of food security, including increasing population and urbanization, changing consumption patterns, conflicts and particular topographical features in certain geographies.

8. Achieving zero hunger by 2030 will require new and existing applications of STI across the food system, addressing all dimensions of food security. Innovative capabilities are critical not only for ensuring nutritious food at all times but also for harnessing agriculture and the broader food system as a driver of economic and sustainable development.

II. Science and technology for food security

9. A number of technologies can play a role in addressing concerns related to the four dimensions of food security (see table). New and existing technologies to combat biotic and abiotic stresses, raise crop and livestock productivity, improve soil fertility and make water available can potentially increase the amount of food produced. Storage, refrigeration, transport and agro-processing innovations can address the dimension of food accessibility. Science to produce high-nutrient staple crops can combat malnutrition, improving food utilization and use. Finally, STI for climate change mitigation and adaptation – including precision agriculture, index-based insurance and early warning systems – can address food instability.

Examples of science, technology and innovation for food security

Food security	*Challenge*	*Examples of science, technology and innovation*
Food availability	Biotic stresses	Disease- or pest-resistant crops Pest-resistant eggplant Rust-resistant wheat varieties Pesticides Herbicides Tilling machines Spatial repellent for on-farm pests Improved agronomic practices (for example, push-pull mechanisms)
	Abiotic stresses	Salt-tolerant crops (for example, quinoa, potato) Climate-resistant crops
	Improving crop productivity (in general)[a]	Conventional breeding Tissue culture and micropropagation Marker-assisted breeding Advanced genetic engineering Low-cost diagnostic toolkits for extension workers
	Improving livestock agriculture (in general)	High-nutrient, low-cost animal fodder Liquid nitrogen and low-cost alternatives for animal semen preservation Low-cost diagnostic toolkits for livestock veterinarians Tissue engineering for laboratory-grown animal products Low-cost veterinary pharmaceuticals (ideally thermostable)
	Lack of water availability[b]	Water storage technologies (subsurface water technologies, aquifers, ponds, tanks, low-cost plastic water tanks, natural wetlands, reservoirs)

Food security	*Challenge*	*Examples of science, technology and innovation*
		Canal irrigation Micro-irrigation technologies, drip irrigation, bubbler irrigation, microsprinkler irrigation Water lifting (hand-powered mechanical pumps, treadle pumps, solar-power irrigation pumps, hydrogen-powered pumps, electric and fossil fuel pumps) Fungal seed and plant treatment for water-related stress Stabilized silicic acid for drought tolerance Irrigation scheduling systems and decision-support systems Planting technology for increased water efficiency Water pads (water-buffering technology) Rainwater harvesting mechanisms Water desalination technologies Wastewater reuse Conservation agriculture Portable sensors for groundwater detection
	Soil	Synthetic and organic fertilizers Biogas digesters Slurry separation systems Zero or conservation tillage Soil microorganisms Natural nitrogen fixation Point-of-use kits for evaluating soil nutrient content
	Need for precise integration, scheduling of inputs for increased yield	Imaging and associated analytics Drones Internet of things Big data Farm management software and applications
	Farming in urban environments	Indoor farming Vertical farming Aquaponics Low-cost greenhouses
	Power and control-intensive operations	Tractors Robotic technologies Animal-drawn implements
Food access	Post-harvest loss (storage, refrigeration, transport)	Fruit preservation technologies Hexanal formulations Thermal battery-powered milk chillers Nanotechnology Improved genetic varieties Seed and grain drying, aeration and storage technology Innovative packaging Biowax coatings Rice parboiling technology Efficient processing technology for pulses Rice-drying technology Cool stores Cleaning, grading and packing technology Off-grid refrigeration Low-cost refrigerated vehicles

Food security	*Challenge*	*Examples of science, technology and innovation*
		Low-cost solar dryers Vacuum or hermetic sealing
	Need for harvest and agro-processing equipment	Crop threshers (motorized and bicycle-powered) Agro-processing technologies (crop, meat, dairy products, fish)
Food utilization and use	Lack of nutritious foods, especially staple crops	High-nutrient staple crops Vitamin A-enriched cassava, maize, orange-fleshed sweet potatoes Iron and zinc-fortified rice, beans, wheat and pearl millet quality protein maize
	Lack of information on healthy diets	Dissemination of nutrition information (for example, health mobile applications)
Food stability	Inability to predict when and how to farm	Weather-forecasting technologies Infrared sensors for detecting crop stress Hyperspectral imaging, based on drones and satellites
	Lack of financial mechanisms to ensure income	Index-based insurance (crops and livestock)

Source: UNCTAD.

[a] STI for improving food availability could include existing technical approaches, along with new and emerging technologies. For example, techniques such as the system of rice intensification can lead to higher average productivity (contribution from the United Nations Educational, Scientific and Cultural Organization (UNESCO)).

[b] Many technologies for addressing water availability were provided as a contribution by the Government of the United States of America.

A. Food availability: Science and technology to improve agricultural productivity

10. FAO identified a food gap close to 70 per cent between the crop calories available in 2006 and the expected calorie demand in 2050.[5] STI can play a critical role in producing more food by creating plant varieties with improved traits, as well as optimizing the inputs needed to make agriculture more productive.

Conventional cross-breeding for improved plant varieties and increased crop yields

11. Genetic modification of plant varieties can be used for nutrient fortification, tolerance to drought, herbicides, diseases or pests, and for higher yields. Earlier forms of genetic modification in agriculture have involved conventional cross-breeding approaches. Although plant improvements are limited to the best traits available within the same family of crops,[6] such technology continues to be useful, especially for smallholder farmers across a number of geographies.

[5] FAO, 2006, *World Agriculture: Towards 2030/2050 – Prospects for Food, Nutrition, Agriculture and Major Commodity Groups,* Interim report (Rome).

[6] S Buluswar, Z Friedman, P Mehra, S Mitra and R Sathre, 2014, *50 Breakthroughs: Critical Scientific and Technological Advances Needed for Sustainable Global Development* (Institute for Globally Transformative Technologies, Berkeley, California, United States).

12. Recent efforts that harness conventional cross-breeding, facilitate capacity-building among farmers and involve North–South cooperation include the Nutritious Maize for Ethiopia project and the Pan-Africa Bean Research Alliance.[7] Other countries use conventional cross-breeding – along with technology transfer – to make staple crops more productive in harsh climactic and environmental conditions. The Government of Peru has been implementing a programme since 1968 to genetically improve cereals for sustainable crop production.[8]

Improving agricultural productivity through transgenic crops

13. Transgenic modification confers a number of benefits, including tolerance to biotic stresses (insects and disease), abiotic stresses (drought), improved nutrition, taste and appearance, herbicide tolerance and reduced use of synthetic fertilizers. Given the challenges of increasing water scarcity and land degradation, such technologies potentially increase productivity per area unit or plant. A number of countries such as Bulgaria, through its Institute of Plant Physiology and Genetics, are developing capabilities in these modern agricultural biotechnologies to increase the tolerance of crops to environmental stressors.[9]

14. Genetically modified crops, which historically have been developed commercially by transnational seed and agrochemical companies, may be costly and externally input-dependent for smallholder farmers,[10] but recent philanthropic initiatives are making such technologies available to them. Given that much biotechnology has been developed in the private sector, there is also concern about technology access, the patenting of life forms, benefit sharing, market dynamics, risk evaluation and mitigation, and related issues.[11]

15. While such issues continue to be debated at the global, regional and national levels, salient challenges for developing countries may involve the innovation capacities to assess, select, diffuse, adapt and evaluate such technologies to address local agricultural challenges, owing to the knowledge intensity of modern agricultural biotechnology.[12] These innovation capacities involve not only human capital, research and development institutions, and enabling infrastructure, but also legal and regulatory policies that promote trade and innovation, recognize traditional and indigenous knowledge, and establish biosafety regulations and institutions that ensure human, plant, animal and environmental safety.[13]

[7] Contribution from the Government of Canada.

[8] Contribution from the Government of Peru.

[9] Contribution from the Government of Bulgaria.

[10] World Bank, 2008, *World Development Report 2008: Agriculture for Development* (Washington, D.C.).

[11] There are differing perspectives on the role of intellectual property rights in genetically improved crops. For more information, see www.iphandbook.org (accessed 21 February 2017); E Marden, R Godfrey and R Manion, eds., 2016, *The Intellectual Property–Regulatory Complex: Overcoming Barriers to Innovation in Agricultural Genomics* (UBC Press, Vancouver); C Chiarolla, 2011, *Intellectual Property, Agriculture and Global Food Security: The Privatization of Crop Diversity* (Edward Elgar, Cheltenham, United Kingdom); UNCTAD–International Centre for Trade and Sustainable Development, 2005, *Resource Book on TRIPS and Development* (Cambridge University Press, New York); J Reichman and C Hasenzahl, 2003, Non-voluntary licensing of patented inventions: Historical perspective, legal framework under TRIPS and an overview of the practice in Canada and the USA [United States], Issue Paper No. 5 (Geneva).

[12] UNCTAD, 2002, *Key Issues in Biotechnology* (United Nations publication, New York and Geneva).

[13] UNCTAD, 2004, *The Biotechnology Promise: Capacity-Building for Participation of Developing Countries in the Bioeconomy* (United Nations publication, New York and Geneva).

Soil management for increasing agricultural yields

16. Genetically improved varieties might not increase yields if constraints such as low soil fertility are not overcome. Synthetic fertilizers have been used to increase agricultural yields for decades but their capital intensity, dependence on natural gas –particularly in the case of nitrogen – and a large ecological footprint make them unsustainable. Fertilizer and water overuse can cause environmental damage and represent an economic waste for smallholder farmers.

17. A number of new technologies and techniques are making more sustainable fertilizer use viable. The National Research Institute for Chemical Technology of Nigeria has developed neem-based fertilizer and organic fertilizer from *Moringa oleifera*, which is environmentally friendly.[14]

18. New methods of nitrogen fixation and other fertilizer components that avoid the current capital- and energy-intensive methods could make nutrient supplementation more environmentally sustainable. For example, "N2Africa" is a large-scale, science-based development-to-research project focused on putting nitrogen fixation to work for smallholder farmers growing legume crops in Africa.[15]

19. New technologies to make biological fertilizers (composting, manure or dung) more viable and effective could also increasingly replace the use of synthetic fertilizers. However, such biological fertilizers, in particular those made from human waste, may require sanitation infrastructure. Furthermore, precision agriculture can help facilitate the precise application of inputs to crop type and soil conditions in ways that increase yields while minimizing potential environmental impacts[16] (box 1).

Box 1. Information and communications technologies for improved soil quality in Bangladesh

The Katalyst programme in Bangladesh aims to increase income for citizens in a number of sectors, including agriculture and food security. The Soil Resource Development Institute of the Ministry of Agriculture partnered with Katalyst to develop a service based on information and communications technologies (ICT) providing farmer recommendations on fertilizer use customized for different crops and locations.

Through an analysis of soil sample data, the service developed recommendations to optimize the cost of inputs and yield. In collaboration with Bangladink and Grameenphone, a mobile-based fertilizer information service was launched, and eGeneration – a local information technology company – developed the software application in the local language (Bangla) with attention to the agricultural users and local context. Since its launch in July 2009, users have incurred reduced fertilizer costs – up to 25 per cent – and higher crop yields – up to 15 per cent. The success has led Katalyst to initiate a similar project for irrigation-related information as well.

Source: UNCTAD, based on information provided by Katalyst in UNCTAD, 2012, *Information Economy Report 2012* (United Nations publication, Geneva).

[14] Contribution from the Government of Nigeria.

[15] Contribution from Wageningen University; K Giller, A Franke, R Abaidoo, F Baijukya, A Bala, S Boahen, K Dashiell, S Kantengwa, J Sanginga, N Sanginga, A Simmons, A Turner, J De Wolf, P Woomer and B Vanlauwe, 2013, N2Africa: Putting nitrogen fixation to work for smallholder farmers in Africa, in B Vanlauwe, P Van Asten and G Blomme, eds., *Agro-ecological Intensification of Agricultural Systems in the African Highlands* (Routledge, London).

[16] Buluswar et al., 2014.

Irrigation technologies: Technologies that make water available for food production

20. Like soil fertility, the availability of water is a critical input for ensuring and improving crop productivity. Approximately 70 per cent of global freshwater supply is devoted to agriculture.[17] Unfortunately, many farmers do not have access to water for agriculture because of physical water scarcity (not enough water to meet demands) or economic water scarcity (lack of investments in water infrastructure or insufficient human capacity to satisfy water demand), among other factors (figure 1). In response to such challenges, low-cost and affordable drills, renewable energy-powered pumps and technologies for desalination and improved water efficiency can potentially make water more available for food production.[18]

21. Lightweight drills for shallow groundwater and equipment to detect groundwater can potentially make groundwater more accessible as a form of irrigation. Solar-powered irrigation pumps could potentially increase access to irrigation where manual irrigation pumps that may be strenuous to use are inadequate or expensive motorized pumps with recurring fuel costs are financially out of reach.[19] Affordable rainfall storage systems are also a potential technology for addressing irrigation.[20]

22. Where diesel- or solar-powered pumps are not feasible, hydropowered pumps can be used to irrigate fields wherever there is flowing water. Greenhouses can mitigate the unavailability of water caused by unpredictable rainfall and enable farmers to have a year-round growing season.

23. Even when groundwater is available, brackish water may not be suitable for human consumption or crop irrigation. Water desalination technologies such as off-grid solar-powered electrodialysis reversal systems can remove salts and minerals from such brackish water.[21]

24. Other technologies improve water efficiency for increased demand for agricultural products in fragile natural environments. For example, new fungal seed and plant treatments can help crops, such as okra, maize, millet and wheat, use 50 per cent less water, with a 29 per cent crop yield increase.[22]

25. Beyond physical technologies and crop inputs, data can be used as a resource to improve water availability and efficiency. In Peru, information access to weather and climate patterns is expensive and limited. The Institute for University Cooperation Onlus provides an irrigation scheduling system that recommends the best irrigation practices based on climate, meteorological and soil data through a mobile platform.[23]

[17] For a more detailed review of agricultural water management technologies, see UNCTAD, 2011a, *Water for Food: Innovative Water Management Technologies for Food Security and Poverty Alleviation*. UNCTAD Current Studies on Science, Technology and Innovation, No. 4 (United Nations, Geneva).

[18] Many of the technologies mentioned in this section were provided as input by the Government of the United States.

[19] Buluswar et al., 2014.

[20] UNCTAD, 2010, *Technology and Innovation Report 2010: Enhancing Food Security in Africa through Science, Technology and Innovation* (United Nations publication, New York and Geneva).

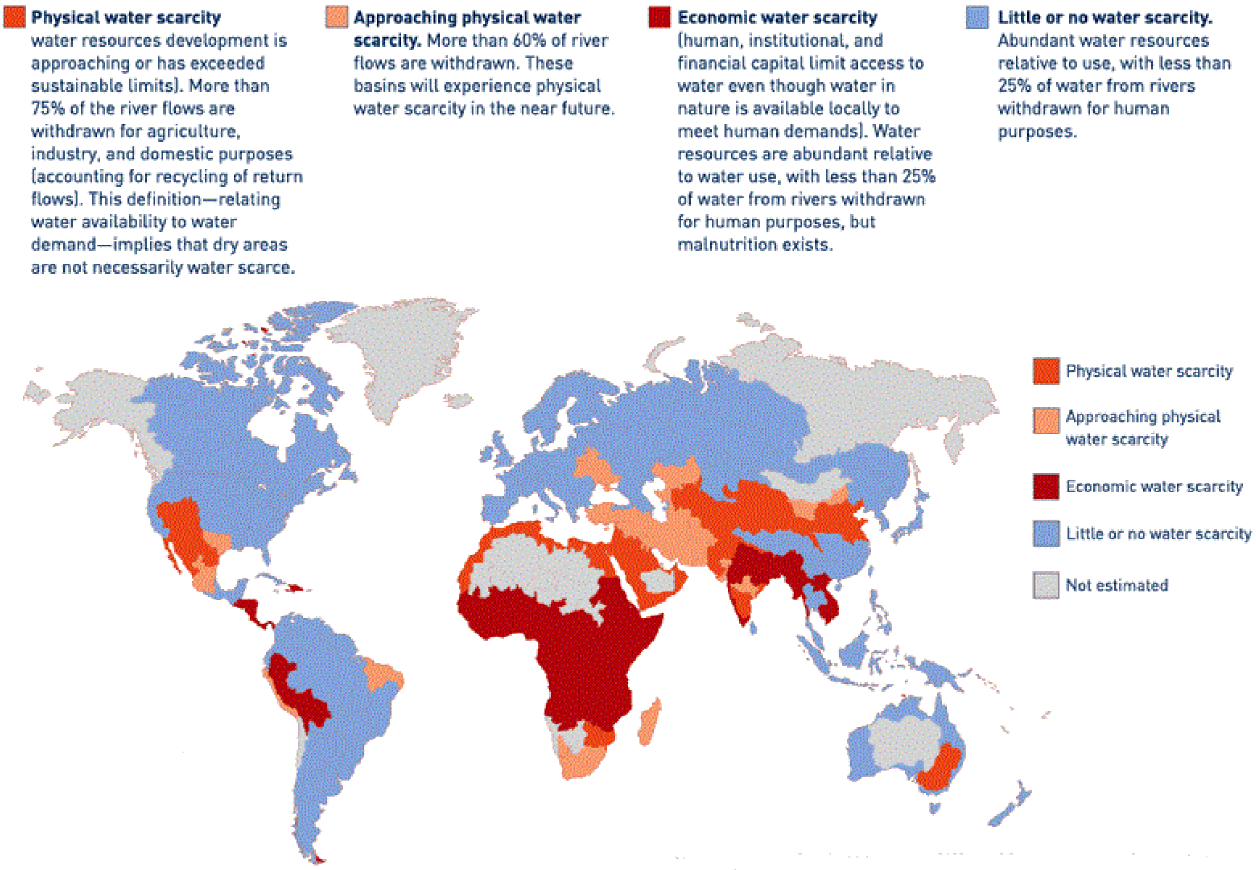
[21] http://news.mit.edu/2016/solar-powered-desalination-clean-water-india-0718; http://securingwaterforfood.org/innovators/edr-mit-jain (both accessed 21 February 2017).

[22] http://securingwaterforfood.org/innovators/adaptive-symbiotic-technologies-bioensure (accessed 21 February 2017).

[23] http://securingwaterforfood.org/wp-content/uploads/2016/03/2015-SWFF-Annual-Report_Press_Print-Version.pdf (accessed 20 February 2017).

26. It is important to address the gender dimension of water for food, as women disproportionately serve as agricultural labour while having limited access to water, among other inputs for increasing agricultural productivity.[24]

Figure 1
Global water scarcity



Source: Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture, 2007 (Earthscan, London).

B. Food access: Technologies for food accessibility

27. A key aspect of accessing food is minimizing food losses during production, storage and transport, and waste of food by retailers and consumers. Such agricultural losses are attributable to a number of factors, including lack of access to ready markets, adequate storage facilities, affordable refrigeration and local crop-processing facilities (figure 2).

28. A number of post-harvest-loss technologies are useful for storage, handling, refrigeration, transport and processing. For example, Uganda is one of eight African countries participating in a project to improve the post-harvest handling, marketing and

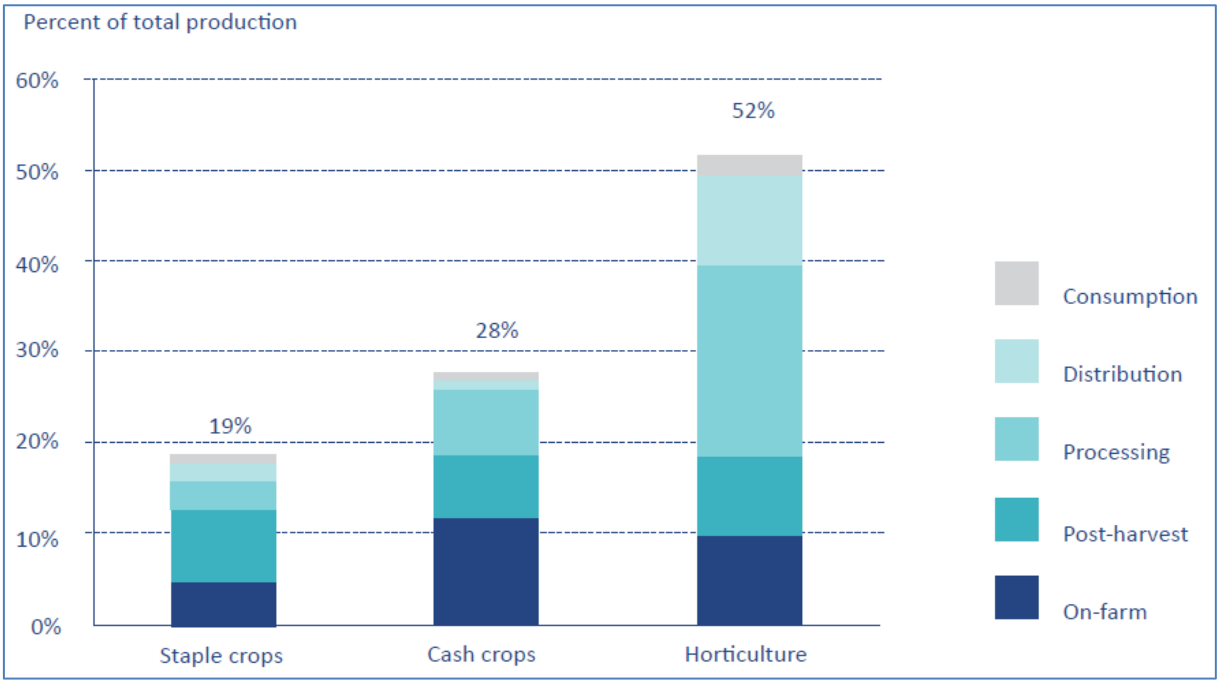
[24] UNCTAD, 2011b, *Applying a Gender Lens to Science, Technology and Innovation*, UNCTAD Current Studies on Science, Technology and Innovation No. 5 (United Nations publication, New York and Geneva).

development of new rice-based products.[25] Other projects include Cuba's[26] meat, dairy and fishery agro-processing and recent efforts to create mobile processing units for cassava in Nigeria.[27] Furthermore, genetically improved varieties can also limit (post-) harvest losses and preserve foods for transport to local, national and international markets.

29. Nanotechnology is being used in a number of projects to improve the preservation of crops.[28] The Canadian International Food Security Research Fund and the International Development Research Centre support a programme to enhance the preservation of fruits in collaboration with five other countries: India, Kenya, Sri Lanka, Trinidad and Tobago, and the United Republic of Tanzania.

Figure 2

Agricultural losses in sub-Saharan Africa across the value chain for different types of crops



Source: FAO, 2011, *The State of Food and Agriculture 2010–11: Women in Agriculture – Closing the Gender Gap for Development* (Rome).

30. Investing in the creation of local talent to fabricate and repair small-to-medium-sized threshers can address the affordability and availability of harvest equipment. Initiatives such as the Soybean Innovation Lab supported by the United States Agency for International Development offer training workshops and have been recently piloted in Ghana.[29]

31. Improving the capabilities of smallholder farmers to produce for regional and international markets could potentially create the economic and financial stimulus to

[25] Contribution from the Government of Uganda.

[26] Contribution from the Government of Cuba.

[27] http://www.dadtco.nl/ (accessed 21 February 2017).

[28] Contributions from the Governments of Canada and Sri Lanka.

[29] Contribution from the Government of the United States.

transcend smallholder farming status. Knowledge aid, where international donors promote the intensification of knowledge for development, could potentially support standards compliance in addition to the development of specific agricultural technologies.[30]

C. Food utilization and use: Science for nutrition

32. One billion people worldwide suffer from insufficient calories and nutrients, 2 billion have sufficient calories but insufficient nutrients, and 2.5 billion consume excess calories, but many with insufficient nutrients. Thus, only about 3 billion people have sufficient but not excessive calories and sufficient nutrients.[31]

33. Biofortification – or the breeding of critical micronutrients and vitamins into staple crops – has emerged as an effective approach to combat malnutrition, especially in developing countries. To date, the most successful example of vitamin and micronutrient biofortification is the orange-fleshed sweet potato, developed at the International Potato Centre.

34. Harvest Plus, based at the International Food Policy Research Institute, has pioneered biofortification as a global plant-breeding strategy for a variety of crops such as vitamin A-enriched cassava, maize and orange-fleshed sweet potatoes; and iron- and zinc-fortified rice, beans, wheat and pearl millet in over 40 countries. These combined efforts have already had a positive effect on10 million people – and several hundred million more stand benefit in the coming decades.[32]

35. Complementary to such efforts, countries such as Guatemala are pursuing comprehensive efforts to improve nutrition while ensuring livelihoods and resilience through the Purchase for Progress programme of the World Food Programme.[33]

D. Food stability: New ways to combat acute and chronic food insecurity

36. The effects of climate change will require sustainable and climate-compatible agricultural practices, including diversifying production.

Adapting food production to climate change

37. STI should focus on re-integrating crop and livestock production and related closed nutrient cycles. Related to this, the mitigation potential of carbon sequestration in optimally managed agricultural crop- and grasslands should be exploited more deeply.

38. Soil carbon losses can be reduced by protecting existing permanent grassland, and soil carbon sequestration can be increased in arable land by the application of organic fertilizers, minimal soil disturbance, agroforestry, mixed cropping and the planting of legumes.

[30] UNCTAD, 2007, *The Least Developed Countries Report 2007: Knowledge, Technological Learning and Innovation for Development* (Sales No. E.07.II.D.8, United Nations publication, New York and Geneva), pp. 161–180.

[31] J Ingram, 2016, What determines food security status? Presented at the International Colloquium on Food Security and Nutrition in the Context of the 2030 Agenda: Science and Knowledge for Action, University of Hohenheim, Germany, 27 September, available at https://gfe.uni-hohenheim.de/fileadmin/einrichtungen/gfe/Dateien/HLPE_John_Ingram.pdf (accessed 21 February 2017).

[32] https://www.worldfoodprize.org/en/laureates/2016__andrade_mwanga_low_and_bouis/ (accessed 21 February 2017).

[33] Contribution from the Government of Canada.

39. In particular, STI for climate change mitigation and adaptation should focus on information provision and knowledge transfer and should include social, as well as technical innovations. Many practices, however, deliver both, and many of the effective adaptation, resilience and mitigation approaches to a changing climate offer important ecological, agronomic, economic and social co-benefits.

40. In addition, locally adapted breeding for drought or heat-tolerant crop varieties, with a focus on underutilized crops, has great potential to support climate change adaptation in agriculture.

41. A forum for sharing experiences on the application of STI to address climate change, including food production and security, is the annual Subsidiary Body for Scientific and Technological Advice research dialogue.[34]

Using big data and the Internet of things for precision agriculture

42. Big data and the Internet of things can be harnessed for a number of agricultural applications, including farmer decision support, precision farming and insurance. A programme coordinated by United Nations Global Pulse, the Indonesian Government and the World Food Programme used public tweets mentioning food prices to develop a real-time food index.[35] In addition, the International Centre for Tropical Agriculture uses big data on weather and crops to better adapt to climate change.

43. The International Livestock Research Institute created a programme known as index-based livestock insurance to provide financial protection based on a rainfall index to trigger payments for pastoralists in the Horn of Africa.[36] Results of a household survey on impact evaluation in that region demonstrate that households insured by the programme were less likely to reduce meals or sell livestock and more likely to have veterinary services, higher milk productivity and more nourished children.[37]

44. Because data relating to meteorology and the Internet of things are increasingly valuable as agricultural inputs, a number of new initiatives focus on sharing data to support agricultural productivity. For example, the Global Open Data for Agriculture and Nutrition initiative, a network of over 430 partners, focuses specifically on the universal benefits of open data ownership and governance, with particular attention to capacity-building for grassroots initiatives in developing countries.[38]

45. Despite the potential of big data and the Internet of things, stakeholders have expressed concern about the privacy and security concerns of agricultural data, the politics of data ownership and transparency, data breaches and the access of smallholder farmers to such data.

Early warning systems

46. Eighty per cent of the estimated 1.4 billion hectares of global cropland is rain-fed, accounting for approximately 60 per cent of worldwide agricultural output.[39] Accurate and

[34] Contribution from the United Nations Framework Convention on Climate Change.

[35] United Nations Global Pulse, http://www.unglobalpulse.org/nowcasting-food-prices (accessed 14 February 2017).

[36] https://www.worldfoodprize.org/en/nominations/norman_borlaug_field_award/2016_recipient/ (accessed 21 February 2017).

[37] https://cgspace.cgiar.org/bitstream/handle/10568/66652/ResearchBrief52.pdf?sequence=1&isAllowed=y (accessed 21 February 2017).

[38] Contribution from Global Open Data for Agriculture and Nutrition.

[39] http://securingwaterforfood.org/wp-content/uploads/2016/03/2015-SWFF-Annual-Report_Press_Print-Version.pdf (accessed 21 February 2017).

reliable weather forecasts enable farmers, especially those near the equator, to capitalize on rainfall for crop production in regions of extreme weather variability.

47. Global systems have played critical roles in disseminating country and region-specific information to help farmers maximize productivity. These include the Global Information and Early Warning System on Food and Agriculture, and Rice Market Monitor (FAO); the Famine Early Warning System Network (United States Agency for International Development) the Early Warning Crop Monitor (Group on Earth Observations) and the cloud-based global crop-monitoring system called Crop Watch (Chinese Academy of Sciences) (box 2). Regional initiatives such as the Regional Cooperative Mechanism for Drought Monitoring and Early Warning in Asia and the Pacific (Economic and Social Commission for Asia and the Pacific) and the Trans-African Hydro-meteorological Observatory also make high-quality data available to their respective regions to improve crop productivity and food security.

Box 2. Crop Watch: Cloud-based global crop-monitoring system

Crop Watch, which is being developed and operated by the Institute of Remote Sensing and Digital Earth of the Chinese Academy of Sciences, supports emergency responses through the periodic release of agricultural information across the world. Taking advantage of multiple new remote-sensing data sources, Crop Watch adopts a hierarchical system covering four spatial levels of detail: global, regional, national (31 key countries, including China) and "subcountries". The 31 countries encompass more than 80 per cent of the production and export of maize, rice, soybean and wheat. The methodology uses climatic and remote-sensing indicators on different scales. The global patterns of crop environmental growing conditions are first analysed with indicators for rainfall, temperature, photosynthetically active radiation and potential biomass. On the regional scale, the indicators pay more attention to crops and include factors such as the vegetation health index, vegetation condition index, cropped arable land fraction and cropping intensity. Together, they characterize crop situation, farming intensity and stress.

Source: Chinese Academy of Sciences Institute of Remote Sensing and Digital Earth, Digital Agriculture Unit.

E. Convergence of new and emerging technologies

48. The convergence of a number of emerging technologies, such as synthetic biology, artificial intelligence, tissue engineering, three-dimensional printing, drones and robotics, may have profound impacts on the future of food production and food security. Many of these applications are currently in the research and development or demonstration phase in developed countries. However, such technologies have the potential to reshape the future of food production, either individually or as part of converged applications.

49. Recent advances in biotechnology have created a new approach to genome editing (the transformation of nucleotide sequences) based on clustered regularly interspaced short palindromic repeats (CRISPR) and CRISPR-associated *Escherichia coli*. Based on this method, genome editing can involve inserting disease-resistant genes from related wild plant species in modern plants. Trait improvement through classic breeding in crops can be accelerated by CRISPR-based genome engineering. The method has been tested in commercial crops to increase yield, improve drought tolerance and expand growth in limited nutrient conditions to breed crops with enhanced nutritional properties and to combat plant pathogens.

50. Some innovations have the potential to transform or make obsolete current forms of livestock agriculture. Researchers at the University of Delaware are mapping the genetic

code of African naked-neck chickens to determine whether their ability to withstand heat can be bred into other chickens that are resilient to climate change. Similar work is being conducted at Michigan State University on turkeys resilient to heat waves.[40]

51. As biology becomes an information technology, it may be possible to grow certain foods outside the conventional factory farm model to produce animal products in the laboratory. Start-up companies are developing animal-free egg whites that use less water and land inputs while preserving the taste and nutritional value of hen-borne egg whites. Other companies are making meat and cheese products directly from plants, while some academics and researchers are leveraging advances in tissue-engineering technologies to three-dimensional print meat. It has been claimed that laboratory-grown meat could potentially use less land and water and produce lower greenhouse gas emissions. On the other hand, if such developments reach industrial scale, it could potentially have implications for livestock agricultural production based in developing countries.

52. Big data, the Internet of things, drones and artificial intelligence may catalyse precision farming, requiring fewer agrochemical inputs for existing agricultural processes. Some companies are using novel genetic sequencing, along with machine learning, to detect soil quality and help improve crop quality. Machine learning is being applied to drone and satellite imagery to build detailed weather models that help farmers make more informed decisions to maximize their yield; it is also being used with plant genomic and phenotypic data to predict the performance of new plant hybrids. Robots are increasingly automating farming through the ecological and economical weeding of row crops.

53. Beyond rural areas, big data and the Internet of things are enabling urban, indoor and vertical farming, which in some cases can improve agricultural productivity and water efficiency with minimal or negligible need for pesticides, herbicides and fertilizers. A number of these technologies (sensors, artificial intelligence, imaging and robotics) can be combined for automated precision farming. The potential impacts of these converging technologies are unclear, leading to the need for robust mechanisms to evaluate such technologies.

54. In order to harness STI for the achievement of food security in 2030, it is essential to manage the risks and public perceptions relating to STI. New technologies have been credited with creating new opportunities but also destroying the status quo, and technological risks are not necessarily confined to the sectors or countries in which are they applied. Potential benefits and positive impacts are often difficult to predict, while risk perceptions can include scientific, technical, economic, cultural and ethical concerns. Managing such technological uncertainty requires scientific and institutional capacities to respond swiftly with available knowledge to both emerging challenges and technological failure.[41]

[40] http://www.latimes.com/nation/la-na-climate-chickens-20140504-story.html (accessed 20 February 2017).

[41] United Nations Millennium Project, 2005, *Innovation: Applying Knowledge in Development*, Task Force on Science, Technology and Innovation (United Nations Development Programme and Earthscan, London and Sterling, Virginia, United States).

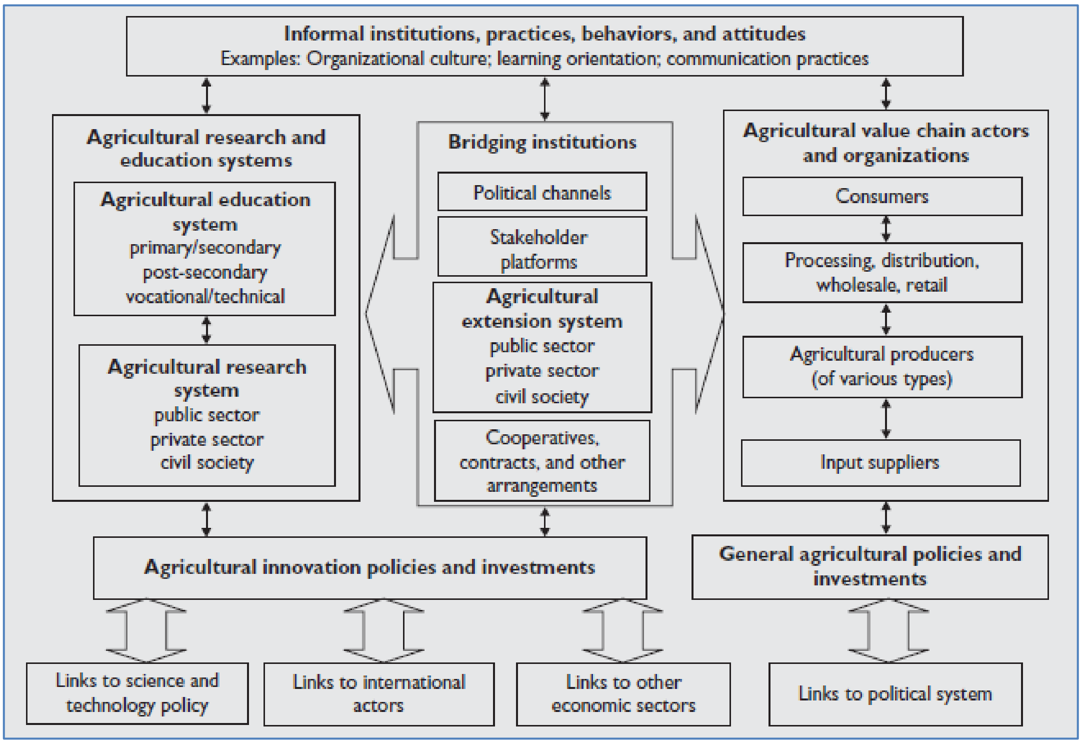
III. Building innovative food systems

55. To harness science and technology for the various dimensions of food security, it is necessary to make the food system itself more innovative. The agricultural innovation system is a useful tool to analyse the ecosystem and supporting mechanisms and infrastructure that facilitate agricultural innovation (figure 3).[42]

56. Designing and strengthening an agricultural innovation system involves promoting research and development, investing in infrastructure, building human capacity, creating an enabling environment and strengthening knowledge flows, particularly among scientists and farmers. Because women account for a significant share of agricultural labour, a gender-sensitive lens to agricultural innovation should be applied. Regional and international collaboration can address research priorities, while international technology assessment and foresight can help countries evaluate the immediate and long-term implications of innovations for food security.

57. The design of innovative food systems should ideally support pro-poor and frugal agricultural innovations, promote the participatory engagement of smallholder farmers, recognize local and traditional knowledge systems, facilitate gender equity and be clearly linked to economic empowerment and livelihoods.[43]

Figure 3
Agricultural innovation system



Source: Larsen et. al., 2009.

[42] K Larsen, R Kim and F Theus, eds., 2009, *Agribusiness and Innovation Systems in Africa* (World Bank, Washington, D.C.); UNCTAD, 2015a, *Science, Technology and Innovation Policy Review: Thailand* (United Nations publication, Geneva and New York).

[43] Adapted from a contribution from E Daño, Asia Director, Erosion, Technology and Concentration Group, the Philippines.

A. Promoting research and development

58. There is an urgent need to increase investment in high-quality research that is coherent with production models adapted to the needs of smallholder farmers. The constantly changing ecological, environmental and biodiversity contexts require continuous research and development to produce inputs and disseminate knowledge that maximizes agricultural yields while safeguarding the environment. At the national level, for example, the Bulgarian Agricultural Academy supports high-quality agricultural research and development,[44] and the Thailand Research Fund has granted more than 800 research projects on foods since 1994 with a focus on local community engagement.[45]

59. Research – at the national and international levels – must address a more complex set of objectives: on the one hand, the new challenges (climate change, renewable energy and energy efficiency, biodiversity and resource management), and, on the other hand, the old challenges (productivity growth and production quality), as well as the promotion of diversification. For example, the Swiss Federal Office for Agriculture is co-leader of the Sustainable Food Systems Programme of the 10-year Framework for Programmes on Sustainable Consumption and Production Patterns,[46] a multi-stakeholder initiative to accelerate the shift towards more sustainable food systems that deliver food security and nutrition for present and future generations.[47]

60. International research institutions, such as the Consortium of International Agricultural Research Centres (CGIAR), are important for the international research agenda on food security. In addition to leading and coordinating international agricultural research, CGIAR could potentially play a greater role as a facilitator and networker, promoting innovation platforms at strategic and international levels, particularly fostering dialogue and clarity of complex phenomena of the sector and its context.

B. Building human capacity

61. The establishment of new education and research programmes and institutions can help create a knowledge base and pool of experts to develop the capacity to innovate within agriculture. For example, the Cuban Institute for Fundamental Research in Tropical Agriculture not only conducts scientific research but also trains talent from Cuba and other countries, including developing countries.[48]

62. Talent-building efforts may include targeted master's programmes at existing applied and research universities, as well as at new university institutes, departments and curricula.[49] This requires significant funds and a long-term commitment. FAO and CGIAR centres, in close collaboration with national agricultural research institutions, could potentially support and coordinate such efforts.

[44] Contribution from the Government of Bulgaria.
[45] Contribution from the Government of Thailand.
[46] Commonly known as the 10YFP Sustainable Food Systems Programme.
[47] Contribution from the Government of Switzerland.
[48] Contribution from the Government of Cuba.
[49] The international master's programme, Safety in the Food Chain, is a potential model for agricultural education (contribution from the Government of Austria).

C. Investing in infrastructure

63. Infrastructure enables many of the scientific and technical applications that address aspects of the food system. More people having access to improved water sources and sanitation facilities and affordable access to water may provide a means to increase the percentage of arable land equipped for irrigation. Ensuring access to affordable, reliable, sustainable and modern energy for all is also important for reducing greenhouse gas emissions while maintaining agricultural productivity.

64. Inclusive, resilient and sustainable development within cities may help build up local markets, provide a means for people to travel to nearby markets to buy agricultural goods and open up new export and import markets. Moreover, ICTs have a critical role to play in food security in general, and with respect to the provision of extension services, insurance, finance and risk prevention in particular.

D. Creating an enabling environment

65. Sustainable agricultural development is possible if effective governance mechanisms take place and policy coherence is fostered between sustainable agricultural development, food systems, environmental concerns, social protection, education, nutrition and health policies and programmes, as well as between their respective institutions, agencies and ministries at the national and international levels.[50]

66. Governance processes can include frameworks for agricultural intellectual property, biosafety and technology and/or risk assessment mechanisms, and multi-stakeholder forums for priority-setting within the agricultural research and development system.

67. Countries may consider encouraging entrepreneurship based on agricultural innovations. For example, the Government of Pakistan supported the creation of an indigenous tractor industry that currently meets 95 per cent of local demand. Public and private efforts helped build local manufacturing capabilities.[51] Similarly, the recently launched Food Innovation Network of the United Kingdom of Great Britain and Northern Ireland aims to tackle the issues that are currently impeding innovation, productivity and growth in agri-food and drink businesses in that country.[52]

68. If food security is considered to be a critical component of a broader innovation-driven development agenda and supported by the highest levels of Government, sufficient political will can exist to facilitate interministerial and intersectoral coordination and collaboration.[53] The e-agriculture strategy guide and toolkit, jointly prepared by FAO and the International Telecommunication Union, demonstrates potential synergies among ICT and agriculture ministries.[54]

[50] High-level Panel of Experts on Food Security and Nutrition (HLPE), 2013, Extract from the Report *Investing in Smallholder Agriculture for Food Security*, Summary and Recommendations (Rome); HLPE 2014, *Food Losses and Waste in the Context of Sustainable Food Systems* (Rome); HLPE, 2016, *Sustainable Agricultural Development for Food Security and Nutrition: What Roles for Livestock?* (Rome); UNCTAD, 2015b, *The Least Developed Countries Report 2015: Transforming Rural Economies* (Sales No. E.15.II.D.7, United Nations publications, New York and Geneva).

[51] Contribution from the Government of Pakistan.

[52] Contribution from the Government of the United Kingdom.

[53] An example of food security policy is the Plan for Food Security, Nutrition and Hunger Eradication 2025 of the Community of Latin American and Caribbean States (contribution from the Government of Costa Rica).

[54] Contribution from the International Telecommunication Union; see http://www.fao.org/3/a-i5564e.pdf (accessed 21 February 2017).

E. Strengthening knowledge flows

69. Extension services can help farmers with a range of issues, including agronomic practices, natural resource management, livestock health and management, accessing financial support and accessing markets and/or market intermediaries.

70. ICTs can improve the quality, reach and efficiency of extension services. The potential benefits of ICTs do not necessarily depend on the sophistication of the ICT device, with deployments involving mobile phones, locally produced how-to videos for farmers and participatory radio campaigns. For example, Access Agriculture is an online platform that showcases high-quality agricultural training videos translated into 74 local languages for farmer-to-farmer capacity-building.[55]

71. Public investment in breeding programmes and support for local seed systems that allow the diffusion of locally adapted genetic material, which farmers would have the right to freely save, exchange and market, is a good example of the need for public investment in research and technology diffusion.[56]

72. Examples of seedbank programmes include the Portuguese national gene bank[57] and the Navdanya network of seed keepers and organic producers spread across 18 states in India.[58]

F. Making innovative food systems gender-sensitive

73. Women account for a significant and growing share of the workforce in agriculture worldwide. They comprise about 43 per cent of the agricultural labour force in developing countries and 50 per cent of the agricultural labour force in the least developed countries.[59]

74. Despite their prominent role in food production and processing, women typically have limited access to resources (for example, technology, training, education, information, credit and land) to increase their output and are often excluded from decision-making processes in managing water and other natural resources.[60]

75. Promoting community-driven approaches to the development of new farming technologies and crop diversification can benefit women and smallholder farmers more generally. Extension services can consciously account for gender roles in agricultural and rural development, including through the recruitment of female extension workers.[61]

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55 Contribution from the Swiss Agency for Development and Cooperation.
56 HLPE, 2013.
57 Contribution from the Government of Portugal.
58 Contribution from the United Nations Major Group for Children and Youth.
59 FAO, 2011; UNCTAD, 2015b.
60 UNCTAD, 2011b; FAO, 2010, Gender, FAO Programme: Crops, available at http://www.fao.org/gender/gender-home/gender-programme/gender-crops/en/ (accessed 21 February 2017); UNESCO Institute for Statistics, 2010, *Global Education Digest 2010: Comparing Education Statistics across the World* (Montreal); S Huyer, N Hafkin, H Ertl and H Dryburgh, 2005, Women in the information society, in G Sciadas, ed., *From the Digital Divide to Digital Opportunities: Measuring Infostates for Development* (Orbicom, Montreal); R Meinzen-Dick, A Quisumbing, J Behrman, P Biermayr-Jenzano, V Wilde, M Noordeloos, C Ragasa and N Beintema, 2010, Engendering agricultural research, Discussion Paper 973 (International Food Policy Research Institute, Washington, D.C.); M Carr and M Hartl, 2010, *Lightening the Load: Labour-saving Technologies and Practices for Rural Women* (International Fund for Agricultural Development and Practical Action, Rugby, United Kingdom).
61 J Wakhungu, 2010, Gender dimensions of science and technology: African women in agriculture, paper prepared for the UN-Women Expert Group Meeting on Gender, Science and Technology, Paris,

Furthermore, more emphasis should be placed on encouraging women to become involved in agricultural science and extension.[62]

G. Facilitating regional and international collaboration

76. Knowledge aid can be a tool for providing STI support as a part of official development assistance. This can occur in the agricultural sector where donors can contribute to agricultural research, especially in the least developed countries. With respect to stimulating industry and infrastructure, knowledge aid as a part of official development assistance can focus on value-chain development schemes, foreign direct investment complementation and linkage development, project funding for industrial and physical infrastructure, the promotion of global engineering associations and non-governmental organizations, and the facilitation of South–South collaboration.[63]

77. Regional cooperation can achieve economies of scale to address research priorities for a specific region, as demonstrated by the work of the Forum for Agricultural Research in Africa, the Latin American Fund for Irrigated Rice and the Regional Fund for Agricultural Technology in Latin America and the Caribbean.[64] Funding from international cooperation activities can also be a potential source of funding for developing countries.

H. Conducting technology assessment and foresight for food security

78. Given the increasing convergence and disruptive nature of new, existing and emerging technologies, there is a need for a global initiative that can systematically convene experts from across disciplines to address agricultural technologies and their potential impacts on society, the economy and the environment. Such a global initiative should ideally conduct technology assessment and foresight exercises to evaluate the immediate and long-term impacts of new technologies for food security.

79. An example of technology assessment and foresight carried out within the United Nations system is the *Advanced Technology Assessment System* bulletin, which analyses the implications of new developments in areas ranging from biotechnology, new materials, energy and information technology to new approaches to science and technology cooperation.[65]

80. In its resolution 2014/28, the Economic and Social Council encourages the Commission on Science and Technology for Development to do the following:

> to help to articulate the important role of information and communications technologies and science, technology, innovation and engineering in the post-2015 development agenda by acting as a forum for horizon scanning and strategic planning, providing foresight about critical trends in science, technology and innovation in areas such as food security, the management of water and other natural resources, urbanization, advanced manufacturing and

28 September–1 October 2010, available at http://www.un.org/womenwatch/daw/egm/gst_2010/index.html (accessed 21 February 2017); Carr and Hartl, 2010; I Christoplos, 2010, *Mobilizing the Potential of Rural and Agricultural Extension* (FAO and Global Forum for Rural Advisory Services, Rome).

62 UNESCO, 2007, *Science, Technology and Gender: An International Report* (Paris); American Association of University Women, 2010, *Why so Few? Women in Science, Technology, Engineering and Mathematics* (Washington, D.C.).

63 UNCTAD, 2007.

64 The Regional Fund is widely known by its Spanish acronym, FONTAGRO; World Bank, 2008, *World Development Report 2008: Agriculture for Development* (Washington, D.C.).

65 See, for example, http://unctad.org/en/docs/psiteiipd9.en.pdf (accessed 20 February 2017).

related education and vocational needs, and drawing attention to emerging and disruptive technologies that can potentially affect the achievement of that agenda.[66]

81. The Commission has also conducted multi-year panels on biotechnology[67] and ICT[68] and their implications for development, based on high-level meetings and expert-based reviews. In this context, the Commission is well placed to continue its work as a forum for assessing and anticipating the social, economic and environmental impacts of new and emerging technologies in food security and agriculture.

IV. Findings and suggestions

82. About 795 million people, or every ninth person, is undernourished, the majority of which live in developing countries and rural areas. New, existing and emerging technologies can address the four dimensions of food security. For example, technologies for improving agricultural productivity, methods for improving soil fertility and irrigation technologies can increase food availability. Post-harvest and agro-processing technologies can address food accessibility, biofortification can make food more nutritious and climate-smart STI solutions – including the use of precision agriculture and early warning systems – can mitigate food instability. New and emerging technologies, including synthetic biology, artificial intelligence and tissue engineering, may have potential implications for the future of crop and livestock agriculture. However, harnessing the potential of such technologies for food security requires investments in research and development, human capital, infrastructure and knowledge flows. A favourable environment for agricultural innovation would benefit from an enabling environment, gender-sensitive approaches to technology development and dissemination, and regional and international collaboration. Furthermore, technology foresight and assessment for agricultural innovations must be in place to manage potential technological risks, while maximizing potential improvements to food security.

83. The following findings and suggestions were highlighted by the intersessional panel and put forward for consideration by the Commission at its twentieth session.

84. The intersessional panel of the Commission on Science and Technology for Development encourages Member States to consider the following courses of action:

(a) Increase national support for research and development in agriculture;

(b) Support investments in infrastructure (electricity and road infrastructure), extension services, and marketing, organizational and social innovations to improve food security;

(c) Create coherent policy frameworks that encourage interministerial coordination for food security, provide an enabling framework for agricultural innovation and establish appropriate regulatory frameworks;

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66 Resolution 2015/27 of the Economic and Social Council makes a similar statement.

67 Findings of biotechnology expert group meetings can be found at http://unctad.org/en/docs/iteipc20042_en.pdf and http://unctad.org/en/Docs/poditctedd12.en.pdf (both accessed 20 February 2017).

68 Findings from panel meetings on ICT were published in R Mansell and U Wehn, eds., 1998, *Knowledge Societies: Information Technology for Sustainable Development* (Oxford University Press, Oxford).

(d) Consider supporting vulnerable groups so that their traditional knowledge can be incorporated into research and extension activities;[69]

(e) Build local talent, including by fostering digital skills that are essential to take advantage of technologies relevant to food security;

(f) Promote national gene banks and the protection of national genetic materials;[70]

(g) Explore adaptive policy frameworks that dynamically respond to new innovations, as well as policy sandboxes that allow policymakers to experiment with regulatory mechanisms and assess the impact of new and emerging agricultural technologies;

(h) Consider mainstreaming a gender lens when developing and implementing policies that harness science and technology for food security.

85. The intersessional panel of the Commission encourages the international community to consider the following courses of action:

(a) Promote the sharing and dissemination of key agricultural technologies, especially for smallholder farmers;

(b) Consider how to make available data relating to agriculture, meteorology, the Internet of things, satellites and other data that could help optimize yields and support rural livelihoods;

(c) Work with stakeholders to define appropriate data standards and minimize the potentially negative consequences of data sharing;

(d) Facilitate the exchange of talent (for example, university professors, researchers and students) in the framework of South–South, North–South and triangular cooperation;[71]

(e) Support knowledge aid efforts that build local capacity to develop, use and deploy new and existing agricultural innovations.

86. The intersessional panel encourages the Commission to consider the following courses of action:

(a) Review how STI can address the needs of marginalized groups (small-scale agriculture, micro and small enterprises) in the context of science, technology and innovation policy reviews;

(b) Strengthen the Gender Advisory Board of the Commission in general, and with respect to food security in particular, in collaboration with other United Nations entities focused on agriculture and gender;

(c) Explore how national Governments can secure access to better data sources that feed into extension services, early warning systems and local innovation efforts;

(d) Encourage a culture of sharing not only success stories and best practices but also failures and key challenges, in general, and with respect to agricultural innovations in particular;

[69] Contribution from the Government of Brazil.
[70] Finding proposed by the Governments of Chile and Peru.
[71] Contribution from the Government of the Islamic Republic of Iran.

(e) Create and strengthen networks with academic departments, research institutions and think tanks that conduct research at the interface of development and STI;

(f) Investigate ways and means of conducting international technology assessment and foresight exercises on existing, new and emerging technologies and their implications for food security.