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Sustainable development

Agriculture technology for sustainable development

Report of the Secretary-General

Summary

> A broad portfolio of policies, approaches and inputs is necessary to achieve the Sustainable Development Goals and to end hunger, achieve food security and improved nutrition and promote sustainable agriculture. The application of science and technology in developing sustainable agricultural practices can play an important role in accelerating progress towards achieving the 2030 Agenda for Sustainable Development. Technologies can support smallholder and family farmers in their efforts to sustainably increase productivity and incomes, contribute to the creation of sustainable food production systems and synergize the achievement of other Goals and targets in a holistic and transformative way.

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I. Introduction

1.   The present report has been prepared in response to General Assembly resolution 72/215, in which the Assembly requested the Secretary-General to submit, at its seventy-fourth session, a report on the implementation of that resolution.

2.   In the report, the Secretary-General examines the current technological trends and key advances in agricultural technologies, provides illustrative examples on the transformative use of technologies at scale and makes recommendations for the way forward.

3.   For the purposes of the report, "agriculture" encompasses the crop, livestock, fishery and forestry sectors, and "agricultural technology" is defined as the application of scientific knowledge to develop techniques to deliver a product and/or service that enhances the productivity and sustainability of agriculture.

II. Overview

4.   Agriculture is at the heart of the 2030 Agenda for Sustainable Development and is central to the commitment to "leave no one behind". The majority of the poor and hungry live in rural areas and depend largely on agriculture for their livelihoods. Of a global total of 570 million farms, more than 500 million represent family farms, which produce more than 80 per cent of the world's food in value terms.[1] In addition to producing food, agriculture provides livelihoods for 40 per cent of the world's population. In low-income countries, it contributes to approximately 30 per cent of gross domestic product.[2] Agriculture systems face significant risks, however, and the effects of climate change on agricultural production and livelihoods are expected to intensify over time.

5.   Transforming food and agriculture systems to promote synergies and reduce negative feedbacks across the Sustainable Development Goals calls for sustainable food and agriculture systems that improve efficiency in the use of resources and food production; conserve, protect and enhance natural ecosystems; support rural livelihoods, adequate nutrition and social well-being; increase the resilience of people, communities and ecosystems; and promote good governance of both natural and human systems.[3] The challenge is, there is no one-size-fits-all approach to addressing complex agricultural problems.

6.   Agricultural technologies address a host of sustainable development challenges by leveraging synergies among the Sustainable Development Goals and maximizing their co-benefits. Such technologies can help produce more, healthier and safer food with fewer resources while reducing encroachment on natural ecosystems, including forests and wetlands. However, the applications of agricultural technologies must be evaluated in terms of how those technologies help meet the needs and demands of family farmers with regard to improving productivity and incomes, as well as how they support sustainable development.

7.   Access to and use of agricultural technologies by those living in poverty, as well as by marginalized groups and those in rural areas, can help improve incomes and productivity and make livelihoods more resilient. Technologies also need to support

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[1] Food and Agriculture Organization of the United Nations (FAO), *The State of Food and Agriculture 2014: Innovation in family farming* (Rome, 2014).
[2] Navin Ramankutty and others, "Trends in global agricultural land use: implications for environmental health and food security", *Annual Review of Plant Biology*, vol. 69 (2018).
[3] FAO, *Sustainable Food and Agriculture: An integrated approach*, Clayton Campanhola and Shivaji Pandey, eds. (London, Elsevier, 2019).

sustainable outcomes such as access to land and other natural resources; capacity in sustainable resource management; access to financial services, infrastructure, other assets and labour; and training, education (including digital literacy) and health-care services.

8.   Appropriate agricultural technologies need to be introduced across value chains using a "systems" perspective that goes beyond isolated aspects of production. Above all, the technologies need to serve the goal of inclusion, taking into consideration implications for gender equality and cultural and social values, incorporating traditional and indigenous knowledge and tailoring technologies to respond to local needs and contexts.

9.   A range of organizational innovations, multi-stakeholder engagement, new and strengthened partnerships and novel investment arrangements are needed to ensure that agricultural technologies are applied towards more equitable, inclusive and sustainable production and distribution systems.

III. Challenges

10.   By 2050, the global population is projected to rise to around 10 billion and agriculture will need to produce almost 50 per cent more food, feed and bioenergy than it did in 2012.[4] Some 821 million people were undernourished in 2017, reflecting a third consecutive year of rising hunger after a prolonged decline,[5] 38.9 per cent of adults were overweight or obese and more than 2 billion people suffered from micronutrient deficiencies,[6] reflecting food systems that fail to serve the needs of all. Moreover, rapid urbanization, together with income growth in low- and middle-income countries, is accelerating a dietary transition towards higher consumption of animal products, fruits and vegetables relative to that of cereals, requiring commensurate shifts in output and adding pressure on natural resources.

11.   Climate change and the intensification of natural hazards are threatening crop, aquatic animals/plants and livestock production, albeit in an uneven manner, and poorer countries and communities in low latitudes that are already food insecure are more exposed, less resilient and have fewer resources to cope. Increasing anthropogenic greenhouse gas emissions, including from global food systems, are exacerbating climate change. The spread of transboundary pests and diseases, intensified by international trade, global human mobility and climate change, is growing alarmingly. Plant diseases alone are estimated to cost the global economy $220 billion annually. The challenge is amplified by antimicrobial resistance. Antimicrobials play a crucial role in the treatment of farm animals, but the misuse of those drugs undermines food safety and endangers human and animal health.

12.   Pressures on natural resources risk overexploitation and unsustainable use. The expansion of agricultural land continues to be the main driver of deforestation, with 80 per cent of the 3.3 million hectares of annual forest net loss propelled by agricultural conversion. There is increasing water scarcity in many regions, and water quality has worsened significantly owing to various reasons, including agriculture. Land degradation and desertification have increased, and 29 per cent of the global

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[4] FAO, *The future of food and agriculture: Trends and challenges* (Rome, 2017).

[5] FAO, International Fund for Agricultural Development, United Nations Children's Fund, World Food Programme and World Health Organization, *The State of Food Security and Nutrition in the World 2018: Building climate resilience for food security and nutrition* (Rome, FAO, 2018).

[6] Development Initiatives, *2018 Global Nutrition Report: Shining a light to spur action on nutrition* (Bristol, United Kingdom, 2018).

land area is degraded.[7] Biodiversity is under severe threat, primarily due to terrestrial and aquatic ecosystem degradation and the advancing agricultural frontier, further endangering the resilience of ecosystems.[8]

13.   To adequately feed the global population, food needs to be better distributed and nutritious, and food safety needs to be maintained and improved. Globally, unsafe food is known to cause more than 200 acute and chronic diseases, with the burden of unsafe food disproportionally affecting vulnerable and marginalized people. In addition, each year some 670 million tons of food are lost or wasted in high-income countries (largely at the retail and consumer levels), and 630 million tons are lost or wasted in low- and middle-income countries (mainly at the post-harvest and processing stages).[9] That is equivalent to one third of the food originally intended for human consumption. Food waste contributes to malnutrition and generates greenhouse gas emissions as it decomposes and releases methane.

14.   Globally, food supply chains consume around one third of available energy, primarily in the form of fossil fuels. At the same time, energy poverty is a challenge across numerous food supply chains in developing countries, limiting productivity and yields. A key challenge is to decouple food supply chains from the use of fossil fuel energy without hampering food security or the development of efficient and inclusive food systems.

15.   An estimated 736 million people live below the extreme poverty line worldwide, with rural people making up 79 per cent of the extreme poor.[10] Inequalities are increasing in many countries, with women and youth, as well as indigenous peoples, more likely than others to have limited opportunities and access. In sub-Saharan Africa and South Asia, youth populations are growing; yet young people in rural areas of low-income countries often shy away from working in agriculture and view farming as a low-productivity occupation on the decline. In the absence of decent work opportunities, and without access to social services and protection, they join the flow of internal and international migrants.

16.   Men are more likely to migrate first from rural areas and the agriculture sector, contributing to an increasing proportion of female labour in agriculture. Meanwhile, the Asia-Pacific region is ageing at an unprecedented pace. The population of older persons has nearly doubled from 1990 to 2014; by 2034, the older population is expected to double again and the child population is expected to continue declining in the region.[11]

17.   Fragility, conflict and violence challenge food security and have adverse effects on hunger and nutrition. The share of the world's extreme poor living in conflict situations is on the rise, contributing to massive displacement and rural-to-urban migration. Conflicts and violence reduce food availability, disrupt access to food and cause vulnerable people to lose access to the range of resources necessary for food and agriculture production.

18.   Those challenges materialize across a range of spatial and temporal scales, transcending sectors and boundaries with links and feedbacks that are complicated

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[7] United Nations Environment Programme (UNEP), *Global Environment Outlook, GEO-6, Healthy Planet, Healthy People*, Paul Ekins, Joyeeta Gupta and Pierre Boileau, eds. (Cambridge, Cambridge University Press, 2019).

[8] FAO, *The State of the World's Biodiversity for Food and Agriculture*, J. Bélanger and D. Pilling, eds. (Rome, 2019).

[9] www.fao.org/save-food/resources/keyfindings.

[10] World Bank, *Poverty and Shared Prosperity 2018: Piecing Together the Poverty Puzzle* (Washington, D.C., 2018).

[11] Economic and Social Commission for Asia and the Pacific, "Statistical yearbook for Asia and the Pacific 2014" (United Nations publication, ST/ESCAP/2704, 2014), pp. 1 and 16.

and at times unforeseeable. Identifying and evaluating trade-offs among objectives requires highly context-specific integrated analysis that is sensitive to critical interdependencies across boundaries and domains. Agricultural technologies can be evaluated in that context, both for the opportunities they create and for their differential impacts on stakeholder needs and interests. A shift from technology interventions focusing solely on single components of agricultural innovation towards an integrated and holistic "systems approach" is key to effective actions for sustainable development.

19. As detailed in the next two sections, an extensive portfolio of agricultural technologies is available to help move food and agricultural systems beyond business-as-usual options and provide integrated solutions across food supply chains, with consequential effects across the Sustainable Development Goals.

IV. Technological trends and key advances

20. Harnessing science and technology is indispensable to overcoming the impacts of climate change and other challenges that prevent countries from achieving food security, improved nutrition and sustainable food and agriculture systems. Technologies also need to be applied to reduce the pressures food systems exert on biodiversity and to reduce greenhouse gas emissions.

A. Biotechnologies

21. The potential for biotechnologies to improve agricultural productivity is promising. Based on the definition of biotechnology in article 2 of the Convention on Biological Diversity,[12] the term "agricultural biotechnologies" encompasses a broad range of technologies, including low-tech approaches such as the use of artificial insemination, fermentation techniques and biofertilizers, as well as high-tech approaches involving advanced molecular-based methodologies, including genetic modification, whole genome sequencing and gene editing. They are used for many different purposes, such as the genetic improvement of plants and animals to increase their yields, efficiency or resilience; the characterization and conservation of genetic resources for food and agriculture; plant and animal disease diagnostics; vaccine development; and the production of fermented foods.

22. The costs and benefits of using genetically modified organisms, as well as challenges to access, have generated debates about the promise they hold for meeting agricultural challenges. Genetically modified crops have been adopted by smallholder farmers in several developing and emerging economies to provide herbicide tolerance and/or insect resistance, but the cost of genetically modified seeds can be constraining. In addition, smallholders face the challenge of implementing the management practices required to grow genetically modified crops safely over time. The debate about genetically modified organisms has revolved around their potential implications for food security, the environment, biodiversity, human and animal health and control of the global food system, and the corresponding ethical, regulatory and intellectual property rights ramifications. Many countries have developed biosafety frameworks to control potential risks associated with the use of genetically modified organisms.

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[12] "Any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use."

23. Genome editing (or gene editing), in particular CRISPR-Cas,[13] is a set of techniques for making precise changes to the genetic makeup of a living organism without transferring transgenes across species boundaries. Such techniques have been used to accelerate the development of new crop varieties and improved livestock breeds (e.g., disease-resistant bread wheat, and cattle without horns to help improve animal welfare in the industry). Genome editing is relatively inexpensive, so it has been adopted as the method of choice for genetically improving crops, livestock and fish, including in developing countries. But in the absence of regulatory intervention, there are risks, including the possibility of off-target alterations in the genome that could lead to unanticipated consequences. Moreover, the pace of the development of enabling policy regimes has lagged behind the scientific advancements that propel the technology. There is no agreement on whether genome-edited organisms are genetically modified organisms, and if they are, whether their release for human consumption and/or into the environment would be regulated by the Cartagena Protocol on Biosafety to the Convention on Biological Diversity. While a few high-income countries have been taking decisions on the subject,[14] most low- and middle-income countries are at earlier stages with regard to establishing the regulatory status of genome-edited organisms.

24. Rapid advances in molecular biology and the ancillary engineering and computer science disciplines, increasing human and institutional capacities and significantly lowered costs for gene mapping are generating huge amounts of DNA sequence data. Whole genomes can now be sequenced at faster rates than in the past, and the resulting data can be curated at a miniscule fraction of the cost compared to 20 years ago. That makes gene sequencing a far more accessible technology. Coupled with the development of high-throughput automated phenotyping capabilities, the process of breeding to develop improved and better-adapted crop varieties and livestock breeds can be sped up even further. DNA sequence data on pathogens and other microorganisms in foods can be used for epidemiological surveillance and to track antimicrobial resistance.

25. Digital sequence information has no universally agreed definition; however, the idea is that the possession of physical genetic material is not necessary to derive value from it. Examples of current uses of digital sequence information include increasing feed efficiency and reducing greenhouse gas emissions in livestock, tree conservation through predictive genomics, genomics-assisted breeding programmes in crops and the detection of hybrids in fish.[15] The ownership of such information with regard to genetic resources for food and agriculture is an intensely debated topic. While the amount of privately held digital sequence information is unknown, publicly accessible information includes approximately 1,700 online databases, with infrastructure mainly in developed countries. Biopiracy concerns stem from the belief that, with synthetic biology capabilities, entire organisms, or just genes for commercial products, could be created in the laboratory from digital sequence information. At one end of the spectrum, there are calls to make the data available freely, in support of research and development and innovation, while at the other end there are calls to regulate access to digital sequence information. There is no consensus.

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[13] UNEP, *Frontiers 2018/19: Emerging Issues of Environmental Concern* (Nairobi, 2019).

[14] Syed Shan-e-Ali Zaidi and others, "New plant breeding technologies for food security", *Science*, vol. 363, No. 6434 (March 2019).

[15] J. A. Heinemann, D. S. Coray and D. S. Thaler, "Exploratory fact-finding scoping study on 'digital sequence information' on genetic resources for food and agriculture", background study paper for the Commission on Genetic Resources for Food and Agriculture (2018).

B. Digital technologies

26. Emerging digital technologies present an opportunity to improve the sustainability of food and agricultural systems and bridge critical information and advisory gaps on a scale unimaginable even a decade ago. Such technologies, collectively dubbed "Agriculture 4.0", have the potential to optimize inputs, support early warning systems about plant and animal pests and diseases, manage mechanization more efficiently, enhance food storage techniques, reduce food losses and waste and provide better and more timely information about market demand and seasonal fluctuations.[16] Digital technologies also offer low- and middle-income countries opportunities to "leapfrog" (i.e., avoid or bypass) existing less efficient technologies.[17]

27. Big data in agriculture is being rapidly generated to collect data on the conditions and characteristics of production, processing, distribution and storage throughout agricultural value chains for real-time monitoring. The data are also used to predict (using statistical models) precisely when and where, for example, watering or fertilizing will be needed. Big data can be harnessed for data-driven agricultural applications, including farmer decision-support, precision farming and insurance.

28. Artificial intelligence and machine learning are analytical tools that facilitate data-driven decision-making and can play a crucial role in underpinning sustainable food and agriculture systems. Prediction-based crop improvement uses artificial intelligence and machine learning with plant genomic, phenotypic, agronomic and climatic data to predict the performance of new varieties.[18] Artificial intelligence and machine learning are being used to identify and predict the genetic signatures of antimicrobial resistance.[19]

29. Distributed ledger technologies, including blockchain technology, can be applied to reduce inefficiencies and corruption and bring greater accountability, transparency and traceability to food supply chains. They can also enhance trade facilitation, provide greater legal certainty to land-tenure systems and strengthen accountability for compliance with international agreements related to agriculture.[20]

30. While the promise of digital technologies in agriculture is enormous, there are also risks. They include the overconcentration of market power among data and service providers; privacy and security concerns regarding agricultural data and techniques for data validation and storage; potential bias in data collection; the politics of data ownership and transparency; technology dependency and planned obsolescence; and, perhaps most importantly in terms of leaving no one behind, inequality of access to the technologies because of limited digital connectivity in rural areas and lower rates of Internet access among women compared with men. The most powerful applications require high levels of mobile coverage, Internet connectivity, skills and knowledge.

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[16] World Bank, "Future of food: harnessing digital technologies to improve food system outcomes" (Washington, D.C., April 2019).

[17] *World Economic and Social Survey 2018: Frontier technologies for sustainable development* (United Nations publication, Sales No. E.18.II.C.1).

[18] https://qaafi.uq.edu.au/article/2019/04/new-breeding-technology-draws-genomics-paddock-realities-and-computer-power.

[19] Erol S. Kavvas and others, "Machine learning and structural analysis of *Mycobacterium tuberculosis* pan-genome identifies genetic signatures of antibiotic resistance", *Nature Communications*, vol. 9, No. 1 (October 2018).

[20] Mischa Tripoli and Josef Schmidhuber, "Emerging opportunities for the application of blockchain in the agri-food industry", issue paper (Rome, FAO; Geneva, International Centre for Trade and Sustainable Development, 2018).

C. Mechanization

31.   Mechanizing agriculture and food processing systems can increase productivity and wages. Mechanization involves applying different forms of farming power sources in conjunction with appropriate tools, implements and machines. It ranges from simple hand tools to motorized equipment (both stationary and mobile, e.g., tractors, mechanical weeders, combine harvesters, rice threshers and dehullers, tilling machines, etc.), and solar-, wind- and water-powered equipment. Recent mechanization innovations have been in the form of precision agriculture technologies and even autonomous equipment (drones, robots and bots) that enable smarter and more targeted and precise pesticide and fertilizer application, which could reduce agrochemical use for improved human and environmental health.

32.   Achieving sustainable development requires that mechanization meet the needs of farmers and their organizations, in particular family farmers and smallholders, and be accessible and demand-driven to create new business opportunities. Sustainable agricultural mechanization can help address shortages of labour, ease drudgery, increase incomes, enhance productivity and the timeliness of agricultural activities, promote efficient resource use, enable better market access and support measures to mitigate climate-related hazards.[21] Machinery and facilities for harvesting, drying, processing and storage can play a significant role in reducing agricultural losses, resulting in higher production and nutrition per area of land. Mechanization also has the potential to create new and higher-paying jobs in agricultural value chains, making rural areas more attractive to youth and encouraging them to stay.

D. Renewable energy technologies

33.   Renewable energy technologies use wind, ocean, solar, hydrological, geothermal and bioenergy sources to generate energy. Where food losses are high as a result of low access to energy, improving access to clean energy has great potential for providing cost-effective, climate-friendly post-harvest operations to reduce food losses. Expanding renewables in agricultural systems would enable the agro-industry to reduce its carbon footprint, enable the energy sector to provide energy for productive use in agriculture and expand the incomes of farmers by reducing food losses.

34.   Scaling up renewable energy technologies in agriculture requires an integrated consideration of possible trade-offs between the uses of water and energy. In addition, food and non-food uses of biomass have to be considered in relation to local food security and access to land resources. If correctly managed, the diversification in the use of biomass can provide opportunities for income generation, thereby contributing to food security and local development. In that regard, approaches such as the INVESTA methodology support financial, economic, environmental and social (including gender aspects) cost-benefit analyses of renewable energy in food chains.[22]

V. Leveraging agricultural technologies for the achievement of the Sustainable Development Goals

35.   The present section focuses on the use of agricultural technologies with regard to their impact across the 2030 Agenda for Sustainable Development, and addresses

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[21] www.fao.org/sustainable-agricultural-mechanization.
[22] FAO, "Investing in sustainable energy technologies in the agrifood sector (INVESTA)" (2018).

the challenges identified in section III. Examples provided here are indicative and not exhaustive.

A. Food insecurity, malnutrition and unhealthy diets

36.   There is a pressing need for transformative change in how we produce, distribute and consume nutritious food to contribute to healthy diets.[23] New and existing technologies can play a role in addressing those concerns.

37.   Biotechnologies can enhance the nutritional value of major food staples and the productivity of nutrient-dense foods such as vegetables, livestock and fish. More than 150 varieties of micronutrient-biofortified crops that provide higher amounts of vitamin A, iron, and/or zinc have been released in 30 countries across Asia, Africa and Latin America.[24] Genetically improved farmed tilapia and derived strains are faster-growing and are more resistant to disease than other fish, and are suitable for both small-scale and commercial aquaculture.[25] The improved strains have been disseminated in 16 countries. The use of an improved strain by fish farmers in Egypt helped increase yields by 5 per cent.[26] With regard to livestock production, artificial insemination, coupled with locally based selection programmes and herd health services, has been widely adopted to enhance milk yields in the dairy sector. For instance, in 2014, 1.4 million cattle were successfully inseminated in Bangladesh, and produce more milk with a higher retail value.[27]

38.   Precision agriculture uses a combination of integrated technologies, including geospatial systems, drones with advanced optics, satellite information and vast computing power, to optimize agricultural output and profitability, preserve resources and detect nutrient deficiency and pest and disease infestation. Those applications increase yields and boost overall input use efficiency, help extend growing periods and raise cropping intensity (more crops per year) and improve management practices. For example, precision livestock farming allows farmers to better monitor the nutrient requirements of individual animals and adjust their feed correspondingly, which enhances the health of the entire herd.

39.   **Case study.** In China, a 10-year national effort engaged nearly 21 million smallholder farmers across the country's agroecological zones. A comprehensive decision-support programme for integrated soil-crop management was developed that consisted of a crop module to determine cropping strategies based on crop model simulations, and a resource supply module for the optimal use of nutrient and water resources. Following field trials to establish locally contextualized applications, a partnership coordinated by the Government promoted the adoption of enhanced management practices in 452 counties. Average yields increased by 10.8 to 11.5 per cent, while nitrogen fertilizer use and greenhouse gas emissions were reduced by an average of 14.7 to 18.1 per cent and 4.6 to 13.2 per cent, respectively.[28]

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[23] Walter Willett and others, "Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems", *The Lancet*, vol. 393, No. 10170 (February 2019).

[24] Howard Bouis and Amy Saltzman, "Improving nutrition through biofortification: a review of evidence from HarvestPlus, 2003 through 2016", *Global Food Security*, vol. 12 (March 2017).

[25] www.worldfishcenter.org/pages/gift/.

[26] http://blog.worldfishcenter.org/2016/12/improved-tilapia-breeding-program-in-egypt-a-year-in-review/.

[27] BRAC, "Artificial insemination: maximising genetic potential of cattle population in Bangladesh" (June 2015). Available at www.brac.net/images/Artificial_Insemination.pdf.

[28] Zhenling Cui and others, "Pursuing sustainable productivity with millions of smallholder farmers", *Nature*, vol. 555, No. 7696 (March 2018).

40.   Smart farms are fully climate controlled, closed or semi-closed greenhouses that can operate year-round, producing highly nutritious foods such as fruit and vegetables at very high yields. Yields can be improved at least 300 per cent compared with traditional open field systems.[29] Sensors are used to more precisely control inputs and environmental conditions, thereby optimizing intensification efforts and limiting water and fertilizer waste. Smart farms are becoming increasingly successful at producing food for cities (with shorter supply chains) and they thrive in locations with harsh natural growing conditions. However, in protected environments, once a microbiological contaminant is introduced, it may multiply quickly.

41.   Vertical farming – growing food in vertically stacked layers for more efficient use of space – uses soil, hydroponic or aeroponic growing methods. Hydroponics entails growing plants without soil using a mineral nutrient solution in a water solvent. Hydroponic plant growth requires up to 90 per cent less water and 75 per cent less space, which is useful in urban areas. The H2Grow project supports vulnerable communities in using low-tech hydroponic units for plant growth in arid environments.[30] It is being implemented in nine countries and reaches 5,000 people, including refugees and internally displaced persons. In Algeria, hydroponic production of animal fodder in refugee camps enabled goats to increase their milk production by 250 per cent, generating income for Saharan refugees. Aquaponics, the integration of hydroponics with aquaculture, whereby fish wastes are used as fertilizers for hydroponic crops, meets the needs of urban agriculture as well as desert areas.

42.   Mobile apps are increasingly used by food producers and consumers to improve nutrition and promote healthy eating habits, as well as improve food safety, by providing easy access to information about nutrient content and food handling and storing. For example, "e-Nutrifood" provides information about the quality and combination of essential nutritional values of food.

B.   Climate change, including emerging transboundary pests and diseases

43.   Swift, real-time information is key to preparedness and timely action to cope with unstable weather and climate conditions. Forecasting services and products allow farmers to better plan agricultural activities, optimize production, manage climate-related risks and integrate climate change adaptation into their decisions.

44.   Digital technologies are used by meteorological agencies to collect, disseminate and analyse agrometeorological and agroclimatological data and information. Basic weather information provided by text messaging can be complemented by more complex information on crop production and protection, water, soil and vegetation, as well as early warning and disaster preparedness. Monitoring and early warning for pests and diseases can be provided to affected countries in order to allow them to respond to emerging situations quickly and effectively. For livestock, the use of individual microchips allows for traceability (origin, vaccination status), thereby facilitating trade and movement of livestock.

45.   **Case study.** In response to the fall armyworm, a new pest in Africa that is rapidly spreading in Asia, the Food and Agriculture Organization of the United Nations (FAO) has developed and established the Fall Armyworm Monitoring and

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[29] Matthieu De Clercq, Anshu Vats and Alvaro Biel, "Agriculture 4.0: The future of farming technology". Available at www.oliverwyman.com/our-expertise/insights/2018/feb/agriculture-4-0--the-future-of-farming-technology.html.

[30] https://innovation.wfp.org/project/h2grow-hydroponics.

Early Warning System (FAMEWS).[31] It uses a mobile phone app to help farmers, communities and extension agents collect and record information on the fall armyworm, as well as a global platform that displays maps and analytics of the field data. Nuru, an artificial intelligence module, complements FAMEWS to help farmers diagnose infestations and take immediate action. The data and maps provide valuable insights on how fall armyworm populations change over time, to better understand their behaviour and guide management practices. Over 55,000 reports from more than 40 affected countries have been collected by the FAMEWS mobile app since its release in March 2018. The FAO Desert Locust Information Service provides a similar service.[32] All locust-affected countries transmit data on locusts to FAO, where the information is analysed in conjunction with weather, habitat data and satellite imagery to assess the current locust situation in a region, provide forecasts up to six weeks in advance and issue warnings on an ad hoc basis.

46. The sterile insect technique uses irradiation to sterilize mass-reared insects for the area-wide prevention, eradication, suppression and/or containment of major insect pests of crops and livestock, minimizing damages to local and regional food production.[33] The use of the technique in Senegal has led to a drastic reduction in the transmission of trypanosomiasis, allowing productive cattle breeds to thrive. In the Dominican Republic, the outbreak of the Mediterranean fruit fly led to a ban on imports by major trading partners, such as the United States of America, Haiti and Japan, resulting in an estimated loss of $42 million in fruit and vegetable exports in 2015 alone. The release of more than 4 billion sterile male flies led to the successful eradication of the pest, reopening the lucrative export market.

47. Farmers must have access to quality seeds and planting materials of a diverse suite of well-adapted crops and their varieties, including those bred with resistance to diseases and pests and adapted to harsher climatic conditions. The potential of genetic resources to address crop production constraints has been unleashed through breeding technologies. For example, the Drought Tolerant Maize for Africa Seed Scaling project enabled farmers in Zimbabwe to harvest over 600 kg more maize per hectare, compared with those using drought-susceptible varieties, translating into an extra income of $240 per hectare.[34]

C. Dwindling natural resource bases

48. Artificial intelligence, using satellite imagery and ground- or drone-based sensors, is transforming land-use planning in countries, including by monitoring deforestation, desertification, biomass fires and peatland degradation. Such data can optimize land-sharing approaches to agriculture and natural resource management, and can help with planning aquaculture development or coastal area management. If governments could maximize the use of artificial intelligence in monitoring illegal logging and forest damage, 32 million hectares of forest could be saved globally by 2030, resulting in an estimated reduction of 29 gigatons of equivalent carbon dioxide emissions.[35]

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[31] www.fao.org/fall-armyworm/monitoring-tools.

[32] www.fao.org/ag/locusts/en/publicat/meeting/topic/1978/index.html.

[33] www.iaea.org/topics/sterile-insect-technique.

[34] Rodney Lunduka and others, "Impact of adoption of drought-tolerant maize varieties on total maize production in south Eastern Zimbabwe", *Climate and Development*, vol. 11, No. 1 (September 2019).

[35] Microsoft and PwC, "How AI can enable a sustainable future" (2019). Available at www.pwc.co.uk/sustainability-climate-change/assets/pdf/how-ai-can-enable-a-sustainable-future.pdf.

49. Terra-i, an online monitoring system, uses satellite data and artificial intelligence to track vegetation changes and tree-cover loss in Latin America in real time.[36] Global Forest Watch is another forest monitoring and alert system that empowers local communities to report and prevent illegal logging operations.[37] Enhanced access to geospatial data and analysis through the Open Foris initiative enables smallholders with a smartphone to better measure and monitor a piece of land as small as an acre to assess deforestation and forest degradation.[38] Open Foris has also been utilized for the collection of dairy industry data in Kazakhstan and animal production by pastoral communities in Chad and Mongolia, and for livestock and pasture development in Tajikistan.

50. Robust and operational methodologies and water- and nutrient-saving technologies exist that allow for the continuous monitoring of land and water productivity by means of open access remote sensing information, for example the WaPOR portal.[39] By providing near real-time information to show how much biomass and yield is produced per cubic metre of water consumed, the methodological framework assists farmers in obtaining more reliable yields, and provides irrigation authorities with information to modernize their irrigation schemes. Tailored end products serve the needs of users at the international, national and field levels.

51. Technologies that enable the mechanization of conservation agriculture[40] (e.g., two-wheeled tractors, single or double disc seeders, etc.) have the potential to greatly improve soil health, which in practice translates to more soil life, a higher soil organic matter content and an enhanced capability by soils to store moisture and retain rainfall/surface water.

52. **Case study.** Nuclear and isotopic techniques can improve agricultural efficiency with regard to water use. For example, a neutron sensor can assess area-wide soil moisture and calibrate satellite imagery to improve early warning systems for flood and drought management. A nitrogen isotope can be utilized to identify factors that affect the efficiency of nitrogen fertilizer use and water quality. In numerous African countries, enhanced productivity of high-value crops such as vegetables has been achieved using small-scale drip irrigation technologies by tailoring watering schedules according to the specific needs and growth stages of crops.[41] In the Sudan, that approach enhanced livelihoods and improved food security for thousands of poor farmers, especially women (many of whom were refugees), yielding an overall additional income of about $550 per family. In Libya, water use for potato crops was reduced by 60 per cent using drip irrigation, while at the same time more than doubling the yield, resulting in water use that was seven times more efficient than sprinkler irrigation.

D. Producing safe food in efficient value chains

53. Contamination of agricultural commodities by naturally occurring agents, anthropogenic activities or from fertilizer or plant protection products can lead to food becoming unfit for human consumption. Examples of technologies to improve food safety include food irradiation, new food packaging, new methods for preservation, improvement in food processing, new varieties that contain lower

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[36] www.terra-i.org/terra-i.html.

[37] www.globalforestwatch.org/.

[38] www.openforis.org/.

[39] https://wapor.apps.fao.org.

[40] A farming system that promotes maintenance of a permanent soil cover, minimum soil disturbance (i.e., no tillage) and diversification of plant species.

[41] www-naweb.iaea.org/nafa/swmn/soils-progress-report.html.

naturally occurring toxic substances and varieties that do not absorb toxic heavy metals from the soil or water. Nonetheless, technology is not a substitute for good handling and hygiene standards, which must be part and parcel of effective management strategies for ensuring food safety.

54. **Case study.** Maize crops (and other staple foods) can be contaminated with mycotoxins – toxic metabolites produced by a naturally occurring fungus, the most prominent being aflatoxin, a potent liver carcinogen. Populations in countries where maize is a staple crop are chronically exposed to aflatoxin, and there have been repeated cases of acute aflatoxin poisoning. Technologies can help manage aflatoxins, and include improved handling and storage conditions to reduce insect and water damage; the improved sorting of grains; the use of Aflasafe, a biocontrol technology that uses competitive exclusion to favour the proliferation of non-aflatoxigenic fungal strains; breeding for aflatoxin resistance; and rapid-testing kits for screening.

55. E-certification systems can enable the efficient flow of safe food. Food surveillance and outbreak investigations demand traceability that reaches far back into the supply chains to identify, prevent or limit any public health threat from contaminated food. The integration of suitable data systems at an international level will be necessary to support food safety monitoring across borders. Blockchain and distributed ledger technologies are some of the promising innovations that may aid in that goal. While progress has already been reported in isolated instances where strong vertical integration was available, more efforts will be necessary for a cross-platform, transnational connectivity that enables safety monitoring while also guaranteeing the protection of privacy and the intellectual property rights of all parties.

56. Whole genome sequencing is an effective tool for food monitoring and outbreak investigation. The success of that technology will be multiplied if traceability systems are implemented across entire value chains. Integration is still in its infancy and challenges remain, including the establishment of suitably enabling policies, particularly with regard to data sharing. Those policies will need to balance key international agreements such as the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity, as well as other applicable intellectual property and privacy rights with interests related to national sovereignty.

57. Farming systems near or adjacent to human settlements should employ technologies to maximize resilience, sustainability and health. Technologies can be employed to harvest nutrient sources from urban organic waste, and pest and weed control technologies can be employed that do not have a negative impact on the health of soil and water or on biodiversity and human health.

E. Unsustainable energy use

58. Energy-smart food systems represent a key component in transitioning to sustainable food and agriculture. Renewable and efficient energy technologies can be implemented at various stages of food supply chains, from on-farm mechanization to food transport, storage and handling to value-added processing and distribution of food. There are opportunities to improve energy efficiency through the cooperative distribution of produce to reduce transportation-related emissions, and through the integration of urban and rural production and processing.

59. Examples include biogas-powered milk chillers, windmills for grinding grains and legumes, solar-powered irrigation pumps, rechargeable batteries for ultra-low-volume sprayers (for pesticides) and solar-powered radios and televisions to communicate field-level information on agriculture and rural life. In aquaculture, solar power can be an important energy source for energy-intensive operations such

as land-based shrimp farms. Integrated aquaculture-solar farms are currently being tested that result in dual benefits, including reducing the energy used to heat water for farming and producing renewable energy.[42]

60.　**Case study.** Access to fresh water needed for use in biogas digesters is a huge barrier for farmers, especially in areas that experience water stress. A slurry separation system has been shown to greatly reduce water demand (up to 80 per cent) for the production of biogas, while creating fertilizer for the fields from unwanted waste products.[43] More than 800 biogas digesters have been installed in Uganda, Mozambique, Togo, Ethiopia and Haiti. Water by-products are separated during the process and reused to mix with organic wastes later in the system. In Uganda, Rwanda and Ethiopia, 11,000 tons of water was recycled during a three-year period using that approach.[44]

F.　Rural development

61.　While digital technologies can lead to the further marginalization of rural communities, when effectively utilized they can be powerful instruments to support smallholders, provide alternatives to migration and facilitate youth entrepreneurship.

62.　Secure and formal property rights are crucial to family farmers and rural communities, but traditional land registry systems are often low-tech, inefficient and prone to error and fraud. Distributed ledger technologies offer a secure, inexpensive and fast method to register land titles. An immutable land title helps build smallholders' endowments of assets and provides them with bankable collateral and access to formal credit, which they often lack.

63.　Digital technologies can also greatly promote the financial inclusion of rural communities by offering ways to assess weather, market and credit risks, as well as by overcoming the high transaction costs associated with both index and conventional insurance. Improved access to market information can help increase farmers' sales and prices and reduce price dispersions across markets. The Food Price Monitoring and Analysis[45] tool supports the dissemination of price information to farmers and traders through the AgriMarketplace mobile app, enabling comparisons across markets, commodities and seasons.

64.　E-commerce is an increasingly important market mechanism, with a value estimated at $27.7 trillion in 2016. It brings producers in urban, peri-urban and rural areas closer to consumers, and helps reduce inventory. In China, two companies have set up service stations in villages to help local consumers shop online. Nevertheless, rural households may be reluctant to sell their produce through the Internet, primarily owing to a lack of knowledge and low levels of trust in online transactions. Another example is the Virtual Farmers' Market in Zambia, an app-based e-commerce platform where farmers' surplus of and buyers' demand for crops are advertised and traded.[46] Since 2017, the app has reached more than 1,000 Zambian family farmers with transactions of 150 tons of produce worth $50,000.

65.　E-extension services are being deployed in low- and middle-income countries to overcome barriers to relevant, customized and real-time information while reducing the cost of extension visits and enabling more frequent interaction with farmers. For example, Digital Green has enabled farmers to share knowledge with

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[42] www.akuoenergy.com/fr/les-cedres.

[43] https://securingwaterforfood.org/innovators/green-heat-slurry-separation-system.

[44] www.greenheatinternational.com/projects/decentralised-biogas-systems-for-africa/.

[45] www.fao.org/giews/food-prices/tool/public/#/home.

[46] https://innovation.wfp.org/project/virtual-farmers-market.

one another through the production and dissemination of more than 5,000 locally relevant videos in over 50 languages. In India alone, 15,000 villages and 1.1 million farmers across 10 states have been reached. [47]

66.   **Case study.** E-vouchers sent by text message allow farmers to directly access subsidized farm inputs. During 2017–2018, pilot e-voucher programmes were launched in Mali, Guinea and the Niger. In Mali, 74.3 per cent of targeted farmers collected their vouchers from the suppliers, and 10,207 tons of fertilizer were distributed across four districts. Some 5,000 kits consisting of seeds, fertilizers, and herbicides were distributed in Guinea; 39 per cent of the beneficiaries were smallholders. In the Niger, the programme was implemented in 20 municipalities and 30,838 households, 26 per cent of which were headed by women, benefited. A review of those programmes highlighted several lessons, including the importance of targeting, the need to diversify the contents of e-voucher kits to meet local needs, the need for increased participation of the private sector, the importance of promoting knowledge about the programme and the need to ensure the availability of farm inputs at the proper time during the agricultural season. [48]

67.   Men and women often do not have the same access to, use of and control over technologies. To address the gender divide, information needs to be customized and mobilized in a format that meets the needs and preferences of women farmers. Various projects implemented by the Women of Uganda Network and its partners have resulted in increased confidence by women farmers in the use of digital tools, leading to increased production of quality seeds and a corresponding positive outcome on household incomes. [49]

68.   The Self Employed Women's Association, with 1.9 million members across 14 Indian states and 7 other Asian countries, strengthens the livelihoods and enhances the self-reliance of small-scale and marginalized women farmers and informal sector workers through a bottom-up, demand-driven community approach informed by knowledge of their financial needs. [50] The Association's Rural-Urban Distribution Initiative network was initiated to build inclusive local value chains for its most marginalized members, and to provide them with regular and updated information on market trends and prices, improved seed varieties and the proper use of fertilizers and pesticides. An online platform allowed for digitalization of the system, and in 2018 the total sales turnover for the Initiative's products was $566,000.

69.   FAO, together with the International Telecommunication Union, is leading a global initiative to engage young innovators and entrepreneurs through hackathons and challenges. For example, in the Caribbean, Egypt, Rwanda and Switzerland in 2018, the #HackAgainstHunger project supported young entrepreneurs in identifying practical interventions and approaches to address challenges related to food and agriculture. [51]

VI.   Recommendations

70.   Unless technologies are adapted to the needs of small and medium-sized family farmers, and are combined with significant investment in rural infrastructure as well as the training and education of those who would most benefit from them, agricultural

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[47] www.digitalgreen.org/india/.

[48] World Bank, "Digitizing agriculture: evidence from e-voucher programs in Mali, Chad, Niger, and Guinea", AFCW3 Economic Update working paper (Spring 2019).

[49] ICT update, issue 90 (February 2019). Available at https://cgspace.cgiar.org/bitstream/handle/10568/99720/ICTUpdate90E.pdf.

[50] www.sewa.org/.

[51] FAO, "Tackling poverty and hunger through digital innovation" (August 2018).

technologies may carry the risk of aggravating disparities and existing socioeconomic inequalities.

71. A systems approach to agriculture innovation is essential to ensuring that innovations, including technologies, are aligned towards common objectives, promote collaboration across silos, address problems relevant to farmers and offer incentives and the means to accelerate adoption by smallholders. Such an approach is also essential to enabling interactions and knowledge flows among the different stakeholders in the agricultural innovation system, including farmers' organizations, research institutions, extension services, governments, international organizations, the private sector and civil society.

72. National agricultural innovation systems in developing countries need to be energized and strengthened to overcome technical, economic, institutional, legal and behavioural barriers and tackle ethical and intellectual property rights issues, private sector capacity, trade tariffs and other issues. Countries should be able to make informed decisions while building skills, expertise and capabilities to harness the benefits and mitigate the unintended risks of agricultural technologies. Country-specific assessments must, therefore, be carried out to determine the distinctive needs of smallholders and family farmers based on local context, to pinpoint existing gaps and vulnerabilities and to take stock of technological and/or digital preparedness. On the basis of such analysis, countries should take evidence-based action to identify and promote scale-neutral technologies that consider traditional and indigenous knowledge and are accessible and affordable.

73. Coherent and comprehensive policies that promote multifunctional agricultural development (including e-agriculture), improve the policy and regulatory environment and are tailored to local conditions need to be put in place. Such policies need to be complemented by a reversal of historical underinvestment in food and agriculture innovation systems. It is also imperative that those policies be accompanied by physical infrastructure development and institutional reinforcement, particularly at the rural and village levels; investment in quality health and education services; the mainstreaming of policies that promote gender equality and youth inclusion; tenure rights and access to land, fisheries and forests; the addressing of soil and water constraints; effective rural financial institutions; and social protection programmes.

74. National policies should create incentives to embed technologies within holistic and sustainable approaches, such as agroecology, agroforestry, the diversification of production systems, climate-smart agriculture, conservation agriculture and an ecosystem approach to agriculture, which should also build upon indigenous and traditional knowledge. The best approaches may be characterized by effectively combining and coordinating appropriate technologies with traditional knowledge, for example linking precision agriculture to agroecology.[52] The creation of incentives for the provision of ecosystem services could also constitute additional sources of income in rural areas.

75. Increased adoption of digital technologies should be facilitated by addressing constraining factors on the supply side (such as rural network coverage) and on the demand side (such as skills, knowledge and affordability). Opportunities and training for upskilling and reskilling to adapt to sectoral transformations, in particular for smallholders, women and other vulnerable groups, should be promoted.

76. Enhanced technology transfer to countries most in need is important to ensure that technologies are applied where they are needed most to increase food security

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[52] Véronique Bellon Maurel and Christian Huyghe, "Putting agricultural equipment and digital technologies at the cutting edge of agroecology", *OCL*, vol. 24, No. 3 (May–June 2017).

and reduce pressures on fragile environments. Multi-stakeholder processes leading to technology transfer and adaptation throughout agricultural value chains can enhance the livelihoods of people in rural areas, particularly women, and limit rural-to-urban migration. The uptake and dissemination of technology is context-specific, and that aspect needs to be considered in any technology transfer initiative.

77. In view of the dependency of many countries on the import of agricultural machinery, institutional initiatives to facilitate trade and investment must be promoted. There is a need to encourage measures that can alleviate barriers to inter- and intraregional trade in agricultural machinery. Machinery renting services should be encouraged for the sustainable mechanization of operations in agrifood chains. Given the constraints presented by the lack of after-sales services and spare parts in rural areas, manufacturers and dealers should be provided with assistance to develop repair-and-maintenance networks in remote areas. A conducive national policy environment is essential in order to strengthen the role of the private sector and enhance and scale up local manufacturing capacities. Attention must be paid to promoting safe, efficient, reliable and environmentally sound machinery and equipment.

78. In the area of analytical work, there is a need to further assess and analyse the current agricultural technologies and practices with regard to their respective contributions to the economic, social and environmental dimensions of sustainability. Foresight and scenario-building exercises at regular intervals are required to evaluate and anticipate the impacts of agricultural technologies at all scales. Such exercises can be helpful to identify "hotspots" or unsustainable technologies. They can help inform the development of "green mechanization" technologies to support conservation agriculture. The availability and quality of data on agricultural technologies must be enhanced as such data are key to the development and adoption of appropriate technologies.

79. Technological innovations must be linked to financial innovations such as de-risking strategies, blended finance options and other innovations. Blended finance mechanisms are new institutional models that generate private sector investment in high-impact development projects that might otherwise be viewed as high-risk. These tools, including patient capital and equity investments, can be used to more effectively distribute investments to small-scale enterprises and producers. Such mechanisms can help identify entry points for public sector action and ways to "crowd in" private resources.

80. Data ownership must be clarified and governance arrangements for open data should be developed. Data governance arrangements should increase transparency and serve to build the confidence and trust of poor farmers. For example, the Global Open Data for Agriculture and Nutrition initiative focuses on the benefits of open data ownership and governance, and pays particular attention to capacity-building for grass-roots initiatives in developing countries.[53]

Role of the United Nations in forging global collective action

81. The United Nations, given its legitimacy and global mandates, can play a meaningful and catalytic role in forging a global consensus on regulatory and ethical standards for guiding the research and development of technologies, ensuring that international cooperation for managing those technologies is guided by the 2030 Agenda for Sustainable Development. The Organization's numerous norm-setting bodies, including specialized agencies, treaty organizations and intergovernmental committees, play a central role in global food system governance and harmonization

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[53] www.godan.info/.

in terms of standards and regulatory frameworks, and that role should be further strengthened.

82. The United Nations should continue to leverage its convening power for multi-stakeholder dialogue and consensus-building. FAO has reinforced its role as a neutral forum for open and constructive dialogue and exchange of knowledge on topics ranging from agricultural biotechnologies[54] to agroecology[55] to food safety[56] to agricultural innovation[57] to digital agriculture.[58] At the regional level, the Centre for Sustainable Agricultural Mechanization of the Economic and Social Commission for Asia and the Pacific organizes the Regional Forum on Sustainable Agricultural Mechanization each year to promote regional cooperation and explore the potential for synergistic action. It is necessary to recognize, through such forums, the diversity of family farmers and their different needs in different contexts for scaling up innovation. In particular, demand-driven processes are required to empower family farmers to innovate.

83. The United Nations should build on its various platforms and mechanisms, promoting coherence among them and ensuring that actions and policies regarding technologies are geared towards achieving the global good. They include the Technology Facilitation Mechanism, the Internet Governance Forum, the World Summit on the Information Society Forum, the Artificial Intelligence for Good Global Summit, the Global Pulse initiative and the Commission on Science and Technology for Development, among others.

84. The High-level Panel on Digital Cooperation considers how digital technologies can contribute to the achievement of the Sustainable Development Goals. In a recent report,[59] the Panel identified priority actions, including: building an inclusive digital economy and society; developing human and institutional capacity; protecting human rights and human agency; promoting digital trust, security and stability; and fostering global digital cooperation.

85. Finally, to effectively support multi-stakeholder engagement in leveraging new technologies, the Organization's internal capacity, credibility and coherence must be enhanced. The Secretary-General's strategy on new technologies[60] has committed to accelerating deep-dive analytical work on the impacts of new technologies; increasing understanding, advocacy and dialogue; supporting dialogue on normative and cooperation frameworks; and enhancing United Nations system support to government capacity development.

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[54] www.fao.org/biotech.

[55] www.fao.org/about/meetings/second-international-agroecology-symposium.

[56] www.who.int/food-safety/international-food-safety-conference.

[57] www.fao.org/about/meetings/agricultural-innovation-family-farmers-symposium.

[58] www.fao.org/about/meetings/digital-agriculture-transformation.

[59] High-level Panel on Digital Cooperation, "The age of digital interdependence" (June 2019). Available at www.un.org/en/pdfs/DigitalCooperation-report-for%20web.pdf.

[60] www.un.org/en/newtechnologies/.