Organisation for Economic Co-operation and Development

TAD/CA/GF(2018)1

Unclassified **English - Or. English**

7 May 2018

TRADE AND AGRICULTURE DIRECTORATE
COMMITTEE FOR AGRICULTURE

Global Forum on Agriculture

How digital technologies are impacting the way we grow and distribute food

GFA 2018: Digital technologies in food and agriculture: reaping the benefits

14-15 May 2018
OECD Conference Centre, Paris

This document is presented for information as a background note for the Global Forum on Agriculture 2018 “Digital technologies in food and agriculture: reaping the benefits”.

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JT03431357

How digital technologies are impacting the way we grow and distribute food

1. In September 2017, the world's first entirely machine-operated crop was harvested, having been sown and tended without a human ever entering the field. This milestone illustrates the cutting edge of digital agriculture – sometimes known as "smart farming" or "e-agriculture".

2. In fact, there is a wide range of innovations promising to substantially change the way we grow and distribute food, fibre and fuel: using satellite data to monitor crop growth, land quality, water resources, or other environmental outcomes; combining sensors, automated farm machinery and advanced analytics software to fine-tune and automate agricultural production; machine learning to automate agronomic advisory services and using digital technology to connect farmers in new ways; and experimenting with blockchain technology and other innovative data management systems to improve efficiency and transparency of agri-food value chains. Together, all of these developments hold the promise of achieving more resilient, productive and sustainable agriculture and food systems and enabling comprehensive farm-to-fork traceability.

3. At the core of this innovation lies the increasing capacity to capture, analyse and exchange agricultural data. However, the spectrum of digital applications in agriculture and food sectors is broad – from low-tech solutions that use mobile devices and platforms, to high-tech "digital farms" that make use of integrated systems involving satellites, drones, robotics, sensors and big data analytics.

4. Whether low- or high-tech, being able to make effective use of digital applications requires a great many things. For example, data collection technologies need to be adopted and deployed, in particular in remote rural areas where connectivity issues persist. Data also needs to be shared with people and machines capable of analysing it, meaning that systems and protocols are needed to exchange data while maintaining their integrity and safeguarding individuals' privacy or commercially sensitive information. Finally, services using this data for the production of information need to be available to farmers and other stakeholders along agri-food supply chains.

5. Reaping the benefits of digital technologies in agriculture requires the participation and co-operation of farmers, researchers, private sector, non-profits and government. But these actors often have different interests and face different incentives. Moreover, digitalisation might change the industrial organisation within the agriculture supply chain, including by creating space for new actors.

6. Governments now have the opportunity to shape public policy and regulatory settings in ways that can facilitate the opportunities offered by digital technologies. However, in evaluating whether existing policy and regulatory settings are "fit-for-purpose", many policy questions still need answers.

7. For example, do existing legal frameworks provide adequate clarity about who owns, or who can access, agricultural data? What role is there for governments to set

standards ensuring interoperability between devices and systems in the sector? Should policy makers opt for sector-specific approaches for agriculture, or is a broader digitalisation strategy able to meet the sector's needs? Is there a need for governments to invest in sector-specific digital technologies, such as sensor networks, beyond supporting rural telecommunications and broadband? How can private sector innovation and engagement in agriculture best be encouraged and the benefits of innovation shared?

8. Digital technologies can also be an opportunity for governments to improve the efficiency and effectiveness of existing policies and programmes, and to design better ones. For instance, freely available and high-quality satellite imagery dramatically reduces the cost of monitoring many agricultural activities. This could allow governments to redesign agricultural policies by moving toward more targeted policies or designing policies which pay (or penalise) farmers based on observed outcomes, in particular to address agri-environmental issues. Governments could also use digital traceability systems to streamline customs processes, food safety and animal welfare assessments, or to design new types of consumer-based policies aimed at improving the sustainability of agri-food systems.

9. There are many issues to be explored and debated and ways forward to be identified, to ensure a policy environment that maximises digital opportunities along the agri-food value chain. To this end, the OECD is working to provide practical advice to governments that supports discussions on sound policy and regulatory settings to address the challenges of digitalisation in agriculture and food, and that helps them to embrace digital technologies as a way toward better policy making.

10. This May, the OECD will host a Global Forum in Paris on “Digital Technologies in Food and Agriculture: Reaping the benefits”, where participants will discuss recent developments in the sector, and explore the role of governments in enabling beneficial changes. This event is expected to help the OECD define a strategic plan in this area going forward.

11. For reference, Annex A provides an overview of new data-driven digital technologies applied in food and agriculture, while Annex B outlines key features of the digital transformation of sector.

Annex A. Overview of new data-driven digital technologies in the agriculture and food sectors

Digital technologies

12. The expression “digital technologies” covers a broad range of devices, tools and applications. The OECD’s Recommendation of the Council on Digital Government Strategies defines “digital technologies” as:

> ***ICTs** [information communication technologies], including the Internet, mobile technologies and devices, as well as* ***data analytics*** *used to improve the generation, collection, exchange, aggregation, combination, analysis, access, searchability and presentation of digital content, including for the development of services and apps. (OECD, 2014a).*

13. This annex provides a non-technical overview of key digital technologies that are currently used or being tested for applications in the agriculture and food sectors. Many of these technologies are yet to reach scale; however use cases show that these technologies could potentially solve a range of issues in the food system.

Platforms

14. Digital platforms collate information and promote broader access to, and more effective use of, a range of information and services. A large range of platforms exists[1] but one of the most salient features of the digitalisation is the emergence of platforms that enable commercial or non-commercial transactions between businesses (B2B) between businesses and consumers (b2C) or between consumers (C2C). These digital market place platforms are changing the domestic and international economic and competitive landscape.

15. Other types of platforms provide agriculture and food sector stakeholders a whole range of information, for instance on regulatory environment, and services, . For instance, governments and the private sector are developing platforms in order to register or share information about administrative processes

16. Access to platforms has been greatly facilitated by increased access to the internet and the introduction of the smartphone, which enables constant mobile connectivity and provides individuals with access to a wide range of new applications and services.

Sensors (remote, proximal and in-situ)

17. Sensors measure multiple properties of the physical world and transform them into digital data. They can be regarded as “the interface between the physical world and the world of electrical devices, such as computers” (Wilson, 2008).

[1] A typology of platforms will be made available in OECD (forthcoming 2018), *Online Platforms: A Practical Approach to their Economic and Social Impacts.*

18. Sensors have been integrated in machines for a long time. The data they provided were measured, processed, and acted upon largely in isolation, and then discarded (OECD, 2016). Thanks to progress in massive data transfer and management, the data generated can now be communicated in real time to other machines and integrated with data from different types of sensors using advanced machine learning techniques to support sophisticated cross-analysis (see cloud computing and machine learning below). The diminishing size and cost of sensor technologies allows their integration in a multitude of devices, enabling the Internet of Things and supporting the development of big data. According to the OECD (2010), "precision agriculture and animal tracking" and "transportation and logistics" are some of the most important fields of application.

19. The ability for sensors to act as tracers is of particular interest for logistics chains. For instance Radio Frequency Identification (RFID) uses "radio frequency based communications to allow for contact or contactless reading of identification of entities (products, people or animals), places, times or transactions" (OECD, 2004). RFID tags are typically inexpensive miniaturised chips (the size of a grain of rice), attached to physical objects or a living being which can be read by a specified RFID reader. RFID tags allow users to efficiently collect and distribute, and potentially store and analyse, information on tracked objects, notably on inventory, location, business processes, security control and numerous other attributes. Implanting RFID microchips in livestock and pets allows for identification of animals. RFID is considered to be a building block for the "Internet of things" (see below).2 New research is considering the potential of edible tracers. While still experimental, these could give consumers information about the history of perishable items (where it has been and for how long) or warning of potential contaminants (Chyan et al. 2018).

20. Recent initiatives, both public and private, have substantially advanced the quality and quantity, and lowered the cost, of agricultural information captured via remote sensors. In particular, satellite-mounted sensors are increasingly precise and the number of satellites producing information relevant to agriculture and food has increased enormously in recent years. Satellites also have the advantage of global coverage, homogeneous data and repeated observations creating historical data, and thanks to multiple observations per day they can permit near real time observation.

The Internet of Things (IoT)

21. Originally, the term IoT encompassed sensors simply providing information for use in other systems. However, the term has been extended to devices and objects which, with the support of sensors that gather data and exchange these with one another and with humans, can have their state altered via networks, with or without the active involvement of individuals (OECD, 2015a). The networked sensors in the IoT serve to monitor the health, location and activities of people and animals and the state of production processes

[2] Picard and Alvarenga (2012) mention the example of coats Textiles in the United Kingdom which "developed a "digital thread" with a security code embedded in the thread itself. It is invisible but can be scanned so it can be used to verify the integrity of clothing, parachutes, and so on—basically anything made from fabric. Invisible taggants, whether chemical or biological, can be inserted into a variety of materials or liquids. Spectral techniques have been developed to increase information capacity, allowing sources of product diversion to be identified. Invisible laser-etched code inside a supplier's manufacturing machines can verify the integrity of source down to the machine level."

and the natural environment, among other applications (OECD, 2016). Combined with big data analytics, technologies can empower intelligent systems and autonomous machines.[3]

22. While having enormous potential, use of the IoT creates new regulatory issues. In addition to questions about privacy, interoperability and other standards, there are potential liability issues, requiring a clear identification of responsibilities particularly when a malfunctioning device can have negative social or economic outcomes (OECD, 2016). For the agriculture and food sectors and the trade chain, IoT will require high connection volumes (meaning a large deployment of sensors), but small data traffic, usually low cost, and requiring low energy consumption -- for instance, management of temperature of a warehouse, tracking of transport logistics or fleet management, or smart meters and sensors in agriculture (OECD, 2017b).

Robots

23. Robots can be used to carry sensors to extend the farmers' eyes (in multiple senses), but can also be used to perform actions in the field, to increase productivity and labour costs. Environmental considerations can also motivate use of robots—for example, using a "fleet" of lightweight automated robots rather than a single large tractor to reduce compaction and preserve soil quality. Milking robots have been successful in the dairy industry. Harvesting robots have also been developed (with a particular focus on developing robots for high value crops such as fresh vegetables), although they are still far from mature.

UAVs/drones

24. Unmanned aerial vehicles, or drones, with autonomous flight control, and with lightweight and powerful spectral snapshot cameras can calculate biomass development and fertilisation status of crops. This results in localised farm management advice. Virtual fence technologies allow cattle herd management based on remote-sensing signals and sensors or actuators attached to the livestock (Walter et al., 2017).

25. After a decade of work with unmanned aerial vehicles, recently emerging technologies have developed more user-friendly aerial platforms, such as the multi-copters. Their use as high-throughput phenotyping platforms for real field conditions and also for water stress management increasing temporal and resolution scales could improve capacity to determine important crop traits such as yield or stress tolerance for breeding purposes (Gago et al., 2015).

Big Data

26. ICTs, including the Internet, as well as connected sensors capturing the physical world are increasingly leveraging large volumes of digital data. These large streams of data, and the capacity to combine them, are referred to as "big data" (OECD, 2015a).

27. Increased computer power is in turn enabling the processing and interpretation of those large volumes of data to infer relationships, establish dependencies, and perform predictions of outcomes and behaviours (OECD, 2015b). The access and analysis of these

[3] Augmented behaviour results from technologies and techniques capable of improving compliance with prescribed action. An IoT device can gather data analysed and combine it with other sources to adapt the behaviour of the device itself without human intervention.

large volumes of data can help inform real-time decision-making by combining a wide range of information from different sources.

Cloud computing

28. Cloud computing allows computing resources to be accessed in a flexible on-demand way with low management effort (OECD, 2014b). While the IoT collects data and takes action based on specific rules, cloud computing offers the capacity for the data to be stored and aggregated, to support big data analytics and enable data processing and decision-making (OECD, 2016). Cloud computing and data analytics include improved machine learning applications, operating at a new level of artificial intelligence.

Artificial intelligence (machine learning, cognitive computing)

29. Artificial intelligence (AI) is defined as the ability of machines and systems to acquire and apply knowledge and to carry out intelligent behaviour (OECD, 2016). These AI or cognitive-based technologies help computers interact, reason, and learn like human beings to enable them to perform a broad variety of cognitive tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages and demonstrating an ability to move and manipulate objects accordingly. Intelligent systems use a combination of big data analytics, cloud computing, machine-to-machine communication and the IoT to operate and learn (OECD, 2017a). Machine vision can be applied using a smartphones, using only an application and a picture to be given information about a plant pest. It can also be used to grade crops.

Blockchain

30. A blockchain is a distributed database, replicated across many locations and operated jointly by all users. The decentralisation eliminates the custodian restraints and all the data in the system are digitally encrypted for unique identification. Once added to the blockchain, a record cannot be changed or deleted without the knowledge of all participants. This technology is argued to create transparency, traceability and trust.

31. A Blockchain is also a computational platform to execute small programs (called "smart contracts") as transactions (CSIRO, 2017). A smart contract can digitally facilitate, verify, or enforce the negotiation or performance of a contract without third parties. With a smart contract, transactions happen only if certain pre-set requirements are met, creating accountability for all transactions.

32. There are two separate types of blockchain governance: open blockchain and permissioned blockchain. For open blockchains, anyone can join and participate in the network. They are based on systems of consensus over the registration of blocs of information based on game theory principles that rely on incentive systems to create coordination among competing actors. This system is referred to as the blockchain governance: digital encryption technologies and monetary incentives are used to get a network of users to work concomitantly towards the creation of an incorruptible ledger. Transactions recorded on blockchains are trackable and are irreversible without the consent of all users.

33. Private blockchains are usually permissioned networks with restrictions placed on who is allowed to participate in the network, and only in certain transactions (IBM, 2017). The governance mechanism relies on the selection of the network participants and can depend on compliance with a set of rules put in place by the network starter, for instance, regulatory authority could issue licenses for participation. It can also depend on

a consensus by all network participants, as, for example a consortium. Once an entity has joined the network, it plays a role in maintaining the blockchain in a decentralised manner (IBM, 2017).

Annex B. What does digital transformation of the agriculture and food look like?

34. While the digital transformation is ongoing, several key trends are identified below. More work is needed to develop a better understanding of how these and other trends are changing the food and agriculture system and the implications for policy.

Datafication of production processes

35. Digital technologies allow for the low-cost capture of data on a range of production processes where previously data had not been collected, or only collected intermittently. For example, whereas crop growth was previously monitored by farmers conducting spot checks or assessing parcels in aggregate, drones can now be equipped with infrared cameras, sensors, and other technologies that collect a variety of relevant data to measure crop productivity and inform decisions regarding pesticides, herbicides, fertiliser, and irrigation. Another example is that digital technologies can help track agriculture's impacts on the environment. This "datafication" of production processes unlocks the potential to apply digital analytical techniques to physical and economic processes, to supplement existing knowledge. A related trend is "digitisation", in which existing data and knowledge (perhaps traditionally recorded in paper-based systems) is translated into digital format, also supporting the efficiency of administrative processes.

Data-driven decision-making

36. Digital technologies allow farmers to optimise the management of agriculture practices at a higher level of spatial and temporal resolution. Farm management and productivity can benefit in three main ways:

- **Better insights** into production variables and dynamics due to data collection by machines, sensors and combined sources;
- **Informed decision-making** based on these insights and scenario analyses that balance different measures and options against targeted goals;
- **Sustainable productivity growth** by further automation, robotisation and enhanced control systems

37. Practically speaking, there are four main ways that digital technologies are being used on-farm to achieve these benefits:

- **Information gathering**: diverse sensor systems, from satellite to in-situ sensors and (geotagged) photos on mobile phones provide the management information for performance benchmarking and improvement as well as the proof for compliance with protocols and regulations. Sensors can monitor the functioning of machinery (fuel wages, tyre pressure etc.), progress and management of production as well as animal and plant health (yield monitors, livestock health, behaviour or location monitors, weighing scales, flow sensors etc.), the environment (weather stations, soil sensors etc.), and check the condition of production assets (satellites, drones, nutrient analysis etc.).

- **Positioning and navigation**: the use of GNSS is widely used to guide tractors and machinery. GNSS systems are embedded in mobile tools including telephones and provide the means to link data to locations.
- **(Reactive) field operations (IoT)**: Electronic devices (called actuators, for example a mechanism monitoring the flow of an irrigation system) that help the farmer to improve field operations and respond/react to small differences that are measured by sensors either directly (real time) or indirectly. The ultimate form is the autonomous robot. For instance, tractors are equipped with terminals that accept 'task maps' which prescribe the intensity of field operations. Field operations also produce the 'As-applied' map to document what operations have taken place and how.
- **Data access and processing for decision support** (big data and data analytics): A very important aspect of digitalisation is the access and processing of on- and off-farm data and its integration. Data collected be compared with historical on-farm data to learn from past performance, but can also be combined with agricultural "big data" to support evidence-based strategic and operational decision making. One key example is geospatial analysis (GIS, combining weather, soil, crops, terrain etc.).These data tools include algorithms and models to use/transform data for documentation and to support evidence based decision-making. To be of use to farmers, such analytics should lead to task prescriptions. Increasingly, these tools are becoming cloud-based, meaning that data processing capacity is not limited by on-site storage space (but also may raise issues relating to data security, privacy and data flows).

Traditional suppliers are innovating, and new actors are entering

38. Digitalisation is entering the farm through traditional machinery and input suppliers that have "connected" their products and services. Traditional mainstream suppliers are offering new digital services such as Global Navigation Satellite Systems (GNSS) machine guidance, sensors and (cloud) portals that create additional value and market advantages to their products.

39. In addition, new service providers propose new digital solutions allowing access through the Internet or via smartphones to services which used to be mostly non-tradable, required the physical presence of experts or simply did not exist.

40. For instance, new digital services allow farmers to access agricultural extension and advisory services previously not accessible to producers in remote areas or too costly, facilitating better management of both production and marketing. They provide information about input and production prices, help in connecting supply and demand, and provide training for increasing productivity and the quality of production.

41. Such services allow scattered farmers to organise and solve supply side constraints in relation to scale. Virtual marketplaces, bringing together farmers and traders is a promising way of enabling isolated farmers to connect to markets and increase their livelihood opportunities, reaping the benefits of unexploited trade opportunities, in particular in developing countries.

42. Machine learning can support the identification of pests simply using an application and smartphone camera. Those services use the combination of farm specific

data with big data to provide insights that still need to be acted upon by farmers, or for the automation and optimisation of a range of activities, for instance the pace of water dripping in an irrigation system or variable application rate of pesticides.

Digital technologies help reduce information asymmetries between different actors

43. The agriculture sector does not create data only for its own use. Digital technologies can also help the sector provide proof of compliance with regulations, eligibility for government payments, or simply to provide better, more trusted information on product attributes valued by consumers. The collection and sharing of information about farm activities therefore supports a wide array of legal and economic processes but also allow a repository of agriculture practices proving compliance with regulations from governments or with other private sector standards to be built. In particular they can facilitate traceability, food integrity, and assist in certification. The capacity to transfer data "from farm to fork" in secured and trusted ways enables consumers to access information and act on their preferences (food provenance, agriculture practices or other socio-economic concerns) in ways that were not possible before. The sector also provides important data to non-food downstream sectors for which agriculture provides primary products such as textiles and leather and provides tools to enable those sectors to perform life cycle assessments (LCA) and carbon measurement requirements as well as due diligence more generally.

44. Digital technologies are also being used by policymakers and administrators to improve information flows needed for policies and regulations for the agricultural and food sectors. For example, use of remote sensors can reduce information asymmetries between farmers who receive government payments and administrators responsible for monitoring and control. Another example is that governments can make use of social media, data visualisation technologies and other digital technologies to better communicate with the agriculture and food sector, to improve transparency of government processes and better involve these sectors in policymaking.

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