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Digital transformation in the field towards sustainable and smart agriculture

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Introduction

Global agriculture has been challenged to ensure food security by providing, in a sustainable approach, food, fiber and clean energy. The predicted global scenario is critical: the world population reaching 9 billion in 2050; growing scarcity of land and water resources; climate change and extreme weather events; growing per capita income and urbanization levels; new digitized consumers demanding more nutritious and functional foods; and decreasing productivity gains in some countries. Projections based on patterns of population growth and food consumption indicate that agricultural production will have to increase by at least 70% to meet demands by 2050. Most estimates also indicate that climate change is likely to reduce agricultural productivity, production stability and income in some areas that already experience high levels of food insecurity. Therefore, the development of smart agriculture is crucial to achieving future goals of food security. (FAO, 2010).

In line with the sustainability of the planet, in 2015, the United Nations (UN) launched the 17 Sustainable Development Goals (SDGs) to promote a fairer society that respects the environment. The 17 SDGs constitute a universal appeal to protect the planet and ensure that all people have dignity, in order to lead governments, companies and societies towards a more sustainable and inclusive world.

They serve as a guide for countries to overcome the most pressing environmental, political, and economic challenges. Some of the 17 SDGs can be achieved by actions directly related to agriculture, as illustrated in Figure 1. Thus, SDG 2, Zero Hunger, can be minimized by increasing agricultural production. SDG 6, Clean Water and Sanitation, refers to the sustainable use of water in irrigation activities and agriculture in general. SDG 8, Decent Work and Economic Growth, can be met by promoting actions to improve the conditions of small-scale rural producers and family farmers and by expanding access to information. SDG 9, Industry, Innovation and Infrastructure, can be supported by improving the production chains. SDG 11, Sustainable Cities and Communities, is supported by greater integration between the field and the city. SDG 12, Responsible Consumption and Production, can be achieved by controlling crop losses and food waste. SDG 13, Climate Action, can be achieved by mitigating the risks of climate change and reducing the emission of greenhouse gases in livestock activities. SDG 14, Life Below Water, is supported through the improvement of aquaculture production. SDG 15, Life on Land, can be monitored by mapping land cover use and sustainable agricultural production. Finally, SDG 17, Partnerships for the Goals, is supported by increased information sharing among agricultural partners (Project Breakthrough, 2017).

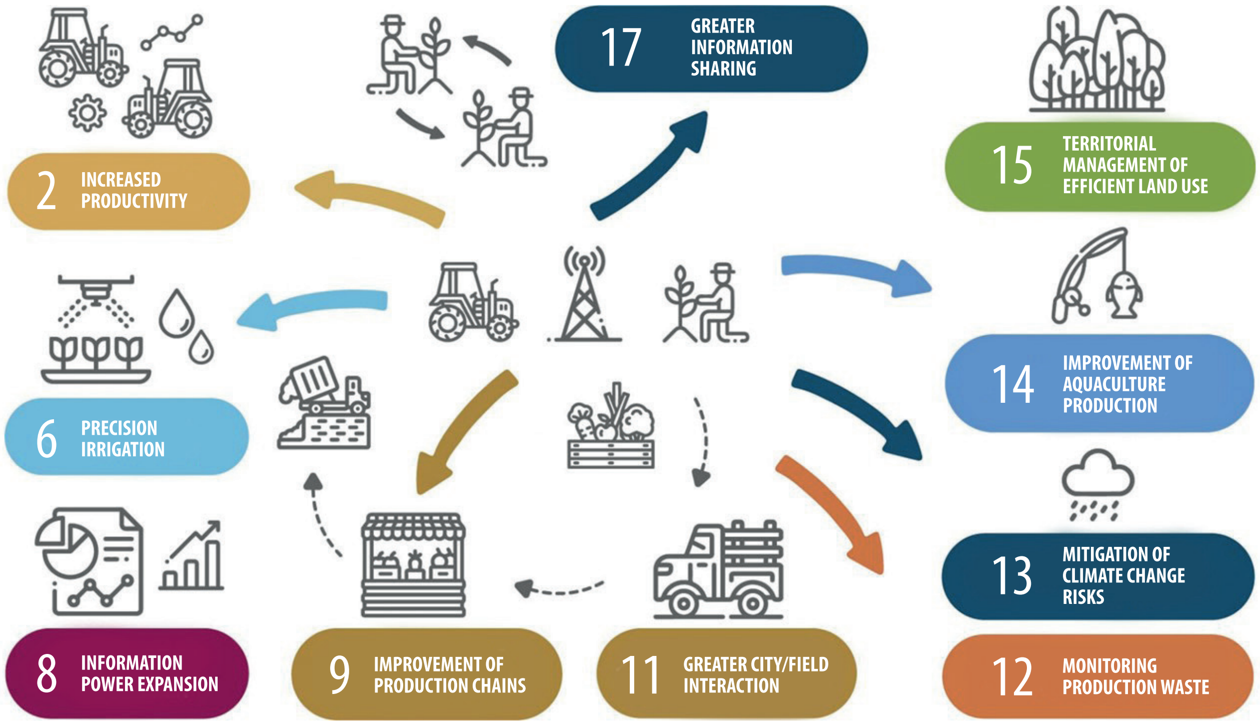

Figure 1. Sustainable development goals related to agriculture.

Source: Adapted from Project Breakthrough (2017).

Among all these challenges, the newest adversity has emerged: the pandemic caused by the coronavirus, which has impacted the health of millions of people, undermining all forms of social coexistence, interrupting education in schools and triggering serious damage to all sectors of the economy, including compromising the agribusiness production and distribution chain, and affecting the price of agricultural commodities. Prins (2020) reports that covid-19 is driving the transformation of agricultural data in three aspects: 1) increased digitization; 2) increased digital collaboration; and 3) visibility, mainly due to disruptions in the value chain, which make planning a fundamental tool in the process of supplying agricultural products. The damage caused by the pandemic is still being calculated, and new policies and strategies will be necessary, not only for risk mitigation, national integration and international cooperation, but also fiscal and economic incentives for the world to return to its development path.

Brazil is the world's largest exporter of soy, coffee, sugar, orange juice, sugarcane ethanol, beef and chicken. In 2019, agribusiness exports were US$ 96.8 billion, representing 43.2% of Brazil's total exports. Brazilian agriculture is based on more than 300 species of crops, and ships 350 types of products around the world, reaching 200 markets on the planet. Brazil is a large producer of grains, meat and fruits, and the agricultural sector accounted for 21.1% of Gross Domestic Product (GDP) and 20% of the workforce (Embrapa, 2019). The Brazilian 2019/2020 grain harvest is considerated as a new historical record, estimated at 250.5 million tons, 3.5% (or 8.5 million tons) higher than the 2018/2019 harvested in (Acompanhamento da Safra Brasileira [de] Grãos, 2020).

In Brazil, family farming is responsible for an important part of the national food production. Approximately 50% of family farming establishments are concentrated in the Northeastern region, 19% in the Southern region, 16% in the Southeastern region, 10% in the Northern region and 5% in the Midwestern region. Bahia is the state with the highest number of family establishments (15%), followed by Minas Gerais (10%). These two states also have the largest areas with family farming establishments, around 10 million and 9 million hectares, respectively (Embrapa, 2019).

In view of all these challenges in agriculture, mainly that of expanding agricultural production without significantly expanding the planted area, the increasingly intense use of new technologies is crucial to enable productivity gains in a sustainable manner. It is in this context that a new production factor has emerged, and which is changing the basis of economic growth for countries across the world: digital transformation. This is a new approach in which Information and Communication Technologies (ICT) play a key role in transforming the strategy, structure, culture and processes of organizations, using the internet power of connectivity.

Through new investments in technologies and business models, it is expected that the engagement of digital customers across all touchpoints in the life cycle of their experience will improve. Digital transformation consists of using ICT to significantly increase the performance and reach of companies by changing the way business is done. There are three elements of digital transformation: transformation of the customer experience, of business models and of operational processes (Transformação Digital, 2020).

Some of the technologies identified as critical in the digital transformation are: cloud computing, internet of things, social media, mobility, big data and data science, artificial intelligence, augmented reality and virtual reality, robotics, ubiquitous connectivity, machine learning, digital twins and automation, in addition to advances in biotechnology and bioinformatics and nanotechnology. These areas, in a synergistic and complementary way, have the power to transform the new world order, culminating in what has been called the fourth industrial revolution, or Industry 4.0. Furthermore, the lower cost of these advanced technologies plays an important role in accelerating innovation (World Economic Forum, 2017).

Disruptive technologies, combined with the latest innovations, hold the promise to leverage agricultural research. The convergence of the areas of Nanoscience, Biotechnology, ICT and Cognitive Science (NBIC) will provide a great qualitative leap in how the world of agriculture can be transformed. The evolution of systems approaches, mathematics and computation, with work in NBIC areas, allows, for the first time, to understand the natural world and cognition in terms of complex and hierarchical systems. Applied both to specific research problems and to the general organization of science and technology institutions, this complex systems approach provides holistic awareness and integration opportunities in order to achieve maximum synergy along the main directions of scientific and technological progress for agriculture (Kim et al., 2012).

The World Economic Forum (WEF) launched the Digital Transformation Initiative, in 2015, in collaboration with the company Accenture (2020), to serve as a focal point for new opportunities and emerging themes related to the latest developments in business digitization and in society. This initiative supports the Forum's actions on themes related to the Fourth Industrial Revolution. Since its inception, the initiative has analyzed the influence of digital transformation on various areas, such as: agriculture, aviation, travel and tourism, chemicals and advanced materials, mining and metals, oil and gas, professional services, retail, telecommunications, automotive industry, consumer sector, electricity, healthcare, logistics, and media (World Economic Forum, 2017).

Digital transformation gave rise to a proliferation of startups, whose most used definition is a group of people looking for a repeatable and scalable business model, working in conditions of extreme uncertainty, according to Yuri Gitahy, angel investor and company founder Aceleradora (2020) and board member of the Brazilian Association of Startups (ABStartups) (Associação Brasileira de Startups, 2019). Startups are highly flexible compared to traditional companies and have a clear goal and speed to adapt, change, create, re-strategize, see and generate new markets and new monetization possibilities. In 2020, ABStartups had more than 13 thousand startups among its affiliates (StartupBase, 2020).

This scenario gives rise to new opportunities to apply these innovations in agriculture. For Brazil to guarantee and expand its production capacity with sustainability, while meeting the global demand for food and nutritional security as a major exporter of agricultural commodities, it requires modernization, technification and innovation across the entire agricultural production chain, converging to digital agriculture as a result of the sector's digital transformation.

According to Embrapa's 2030 Vision document (Embrapa, 2018), ICT and its accelerated advances, such as social media and digital platforms, have transformed relationships, interactions and communication between companies and consumers. Increasingly accessible computers and cell phones, low-cost internet and wi-fi technology enable access to information and provide the consumer a larger role in decision-making when buying, as well as in sharing experiences and in controling products and brands. The advancement of the digital and collaborative economy increases the level of information, the consumers' skills and engagement, as well as the necessary conditions for them to have a leading role in making decisions about productive processes, promoting their empowerment (Gazzola et al., 2017).

It is not surprising that in this era of extensive and profound transformations brought about by ICTs, one of the main forces shaping the future vision of Brazilian agriculture is the influence exerted by new consumers, who are increasingly connected through social networks to promote their consumption choices, while influencing peers and agricultural production systems. Equipped with more information and greater knowledge about products and their prices, these economic agents increasingly become a determinant of the attributes they want, enhanced by digital opportunities and tools. Individuals ever more interconnected with their devices, always connected to the network (web) and with access to any type of information in real time, are strong opinion makers in their circles of influence. This demonstrates that the trust they place in organizations (suppliers) strongly affects their survival. (Embrapa, 2018).

The most recent Brazilian survey by ICT Households of the Brazilian Internet Steering Committee (CGI. br), carried out in 2019, shows that 50% of the Brazilian population has used a computer, 74% uses the internet and 99% has a cell phone (Comitê Gestor da Internet no Brasil, 2019). According to the Census of Agriculture the Brazilian Institute of Geography and Statistics (IBGE), carried out in 2017, the number of farmers who declared having access to the internet grew 1,900%, from 75 thousand in 2006 to 1,430,156 in 2017, with 659 thousand through broadband and 909 thousand through mobile internet (IBGE, 2019). In accordance with the study *The mind of the Brazilian farmer in the Digital Age*[1] by McKinsey & Company, young large-scale farmers, such as grain (32%) and cotton (62%), are the pioneers in adopting precision agriculture in Brazil and in learning about technologies. Among them, 47% use at least one precision farming technology, while 33% use two or more. Furthermore, according to the study, variable-rate

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[1] Presentation of the study by Nelson Ferreira at the webinar Digital agriculture in the post-covid era, on May 7, 2020. Available at: https://www.insper. edu.br/agenda-de-eventos/a-agricultura-na-era-digital-pos-covid

application and drones are the most popular technologies, and many others use the internet of things, telemetry and remote sensing.

In another survey carried out in partnership with Embrapa, the Brazilian Micro and Small Business Support Service (SEBRAE) and the National Institute for Space Research (INPE) (Santin, 2020), 84.1% of the interviewed farmers use at least one digital technology in their production process. The main functions of digital technologies used by farmers are: obtaining information and planning activities on the property (66.1%); rural property management (43.3%); purchase and sale of inputs, products and production (40.5%); mapping and planning of land use (32.7%); and forecast of climatic risks such as frost, hail, *veranico*[2] and heavy summer rains (30.2%).

This chapter will explore the main aspects of digital transformation in agriculture. Section 2 will address the evolution of agriculture and automation in agriculture. Section 3 will discuss the path to fully automated 5.0 agriculture and the key factors involved. Section 4 will present initiatives to promote digital agriculture in Brazil. Section 5 will indicate how to incorporate the digital transformation megatrends in agriculture. Finally, section 6 will present the main contributions of this chapter.

Evolution of agriculture: from Agro 1.0 to Agro 4.0

Agriculture should be considered one of the greatest achievements of humanity. In the early 20th century, there was agriculture 1.0, in which the workforce was provided by the labor of families, using manual instruments, assisted by animal traction. It was low production agriculture. These farmers, in addition to cultivating for their own consumption, generated a food surplus that supported an ever-increasing number of people.

With the Industrial Revolution and the growth of the urban population, demand for food increased, requiring that the various agricultural production processes also evolve. At that time, scientific method and advanced technologies were applied to agriculture, and machines were being created and implemented to assist in the different stages of fertilization, planting and harvesting.

Brazilian agriculture was rudimentary in the middle of the last century, around 1950 and 1960. Manual labor prevailed in agricultural production. At that time, less than 2% of rural properties had agricultural machinery. Farmers suffered from a shortage of technology and information. As a result, there were low yields per hectare and little production. The expansion of agriculture required converting extensive natural areas into crops and pastures. Inappropriate practices caused severe environmental impacts, such as erosion and siltation. However, farms did not produce enough to meet the domestic demand. Inefficiency in the field created problems across the country. Brazil experienced a moment of strong industrialization, with growing cities and population, besides greater purchasing power. The context was that of food scarcity (Embrapa, 2020a).

The Green Revolution took place and introduced a series of technological innovations in the agricultural sector. These innovations aimed to increase productivity through genetically modified seeds, new soil fertilization techniques, the use of industrialized products (such as pesticides), and the intense use of machinery, which significantly shortened the time spent in harvesting process. Careful livestock rearing, crop rotation and better equipment, with the introduction of the combustion engine, helped to increase

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[2] Dry period, accompanied by intense heat, strong insolation and low relative humidity during the rainy season or winter. Similar to Indian summer.

production. Field mechanization became a trend in the early 20th century. Nevertheless, it was only after World War II that manual traction was completely replaced by mechanical force in North American and European crops (Jacto, 2018). The use of all these new technologies culminated in the implementation of Agriculture 2.0.

At that stage, Brazil was a major food importer. Embrapa was created in 1973, and one of its main attributions was to ensure food security, investing in research to consolidate various production chains and to developed technologies to transform the Cerrado biome into productive land. Agriculture was predominantly based on monoculture and research had a monodisciplinary and adaptive vision. The answers emerged after years of research carried out by Embrapa, universities, state agricultural research institutions and, later, by the private sector. With genetic improvement techniques, suitable plants for the Brazilian soil and climate conditions were developed. They were cultivars less sensitive to long days and more tolerant to pests in the tropical world. Soil correction and fertilization were essential contributions. Research was carried out to optimize the use of correctives and fertilizers that allowed planting in Cerrado soils, which until then were considered unproductive. (Embrapa, 2020a).

Later, agricultural intensification was strengthened, and monoculture gave way to integrated and rotated production systems. These systems demanded more knowledge and involved multiple disciplines. Research became systemic, as it was important to understand the entire chain of production systems. (Pillon, 2017).

No-till, climate risk zoning, pest and weed management, mechanization, succession of up to three annual crops in the same area and integrating farming with livestock and forest are additional and valuable approaches and technologies. These results are directly related to investment in research, rural extension, public policies and entrepreneurship. (Embrapa, 2020a).

Since then, technologies have evolved in unimaginable ways, with machines and implements to increase the efficiency of field activities, a trend that became known as precision agriculture, initiating Agriculture 3.0. According to the International Society of Precision Agriculture, precision farming is:

> [...] a management strategy that gathers, processes and analyzes temporal, spatial and individual data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production (Springer, 2020).

Precision agriculture, through machines with built-in sensors, use of satellite images, remotely piloted aircraft, such as drones, and sensors implanted in animals and crops, made it possible to collect numerous types of data, such as information related to soil, climate, plants and animals, application of inputs, yield maps, among others. The large volume of data collected through precision agriculture constitutes a source of information obtained directly from the field (Bernardi et al., 2014).

Currently, driving forces point to technological aspects that consolidate clean production systems, with a positive carbon balance, based on sustainability; bio-based agriculture; advances in synthetic biology; demand for greater efficiency of water use in agriculture; operating in a new energy development cycle; technological disruptions; and increased demand for food, fiber and bioenergy with more efficient use of natural resources and environmental services. Systems become complex and involve many variables. It is the era of bioeconomy, which concerns the economic activity driven by research and innovation in biological sciences (National..., 2012). This includes everything from the production of renewable biological resources to the conversion of these resources and residues into food and non-food products, using the integration of knowledge and technologies generated in different areas (European Commission, 2012). It involves three major elements: advanced use of genes and complex cellular processes to develop new processes and products; use of renewable biomass and efficient bioprocessing to support production; integrating knowledge and applying biotechnology among economy sectors (Organization for Economic Co-Operation and Development, 2009).

Alongside these new agricultural demands, there is digital transformation, as discussed in the Introduction, which brought new disruptive technologies and which started to be used, causing the emergence of digital agriculture and leading to yet another phase of the technological revolution, in other words, Agriculture 4.0. Agriculture 4.0 is an analogy to Industry 4.0, resulting from the digital transformation of the agricultural sector through massive data collection to assist decision-making. Figure 2 illustrates the evolution of agriculture and its respective phases.

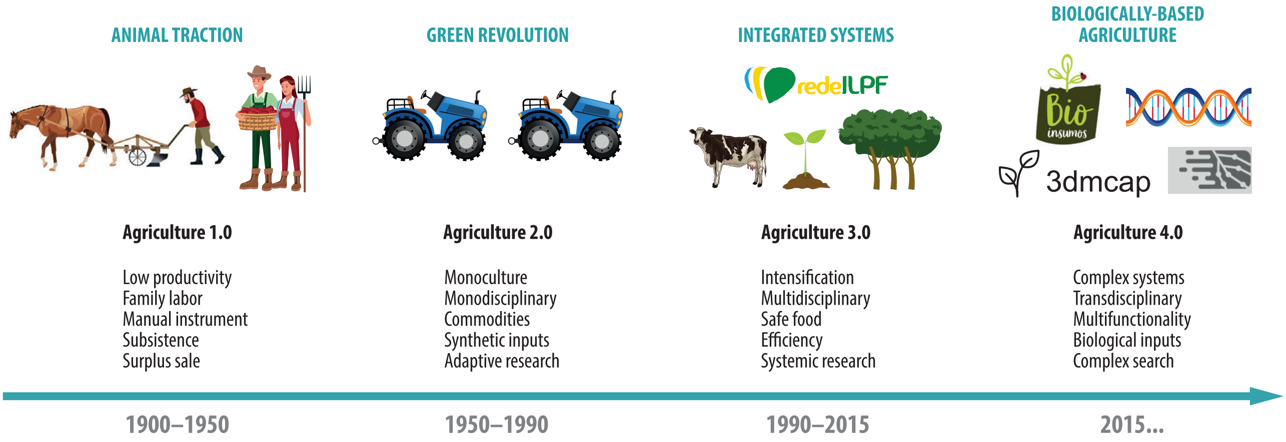

Figure 2. Phases of the evolution of agriculture.

Source: Adapted from Pillon (2017).

The digital transformation in the age of bioeconomy will combine technological advances in disruptive technologies with advancements in biotechnological areas. It will produce solutions for an agriculture that involves the study of complex systems, in which it is increasingly necessary to carry out analyses, monitor and predict, taking into account the social, biological, environmental and economic aspects related to the use of these new technologies.

Digital agriculture: from Agro 4.0 to Agro 5.0

Digital agriculture consists of inserting digital technologies in all stages of the value chain in order to promote competitive advantages and socio-environmental benefits. It is based on digital content, by processing the large volume of data produced in all stages of the production chain, from pre-production to the post-production phases, and covering production, as illustrated in Figure 3. Pre-production includes data for genetic improvement in plants and animals. The production phase involves data collected in precision agriculture by drones, satellites, sensors placed on plants, animals, soil, atmosphere, machines, equipment, and vehicles remotely connected to each other and to a data collection center. Finally, in the post-production phase, data comes from market analysis and from the stages of storage, distribution, logistics, traceability, consumption, among others.

In the pre-production phase, the use of data mining, high-performance computing, and modeling and simulation technologies, along with biotechnology and bioinformatics, will enable the discovery of genes that control complex features and their functions. Together with gene interaction studies, these

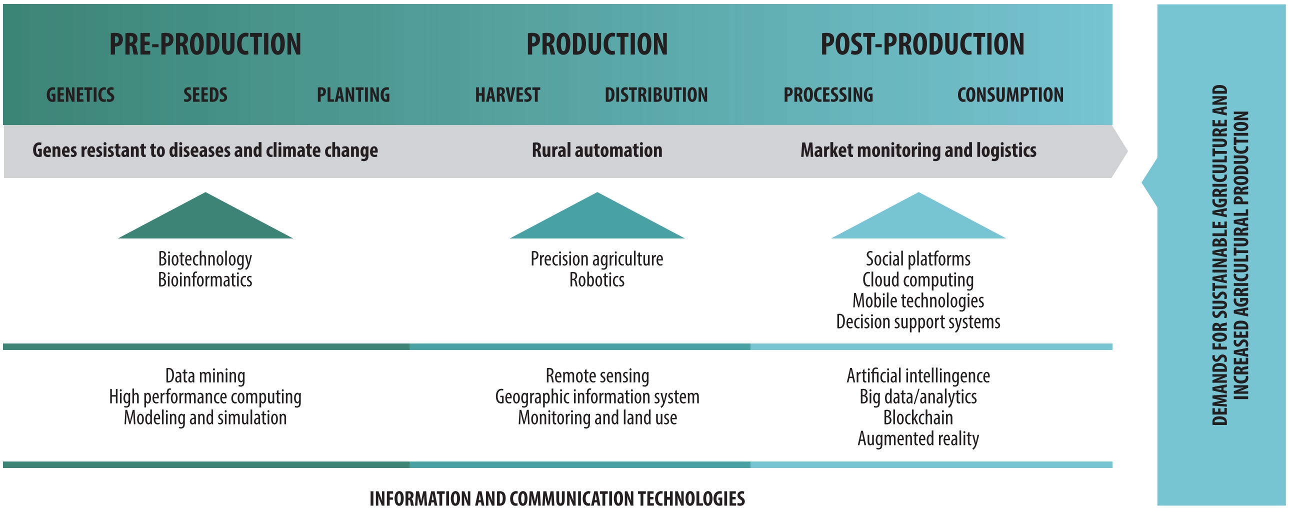

Figure 3. Digital agriculture in the production chain in the pre-production, production and post-production stages.

technologies will promote advances to impact several areas of animal and plant production, such as management, nutrition, resistance to diseases and water stress, health and genetic improvement, resulting in more sustainable products, with better nutritional quality and safety. Integrating the heterogeneous data and the large volume of information generated by the "omics" sciences is a major challenge in the area of integrative genomics. Dealing with the data stored in different places and formats, and combining this with the use of machine learning strategies, mathematics, computational algorithms and supercomputers, will make it possible to explore, in an innovative way, the data generated by different omics sciences (Boyle, 2013; May, 2014). This innovation occurs due to predicting biological functions and understanding biological mechanisms, such as those responsible for diseases, and defining characteristics of agronomic and productive interest.

In this regard, bioinformatics emerged from the need to organize, manage, visualize and exchange biological sequence data. With this information, bioinformatics evolved towards the creation of tools for analysis, interpretation and modeling sequences, structures, genomes, metabolic networks, creating an increasingly complex network of information. Through bioinformatics, it is now possible to perform analyses at different levels of complexity, based on data sets that allow revealing aspects of the complex organization of biological systems through studies in genomics, transcriptomics, proteomics, metabolomics, in addition to the scale of phenotypic analysis of the most varied organisms (Varshney et al., 2014).

Biotechnology, on the other hand, brings innovations such as synthetic biology, which enables the design of an organism, allowing the creation of genetic machines with new properties and operations, for example the generation of plants as biomass raw materials for biofuels and bio factories to produce inputs for the industrial and pharmaceutical sector. Another technology is genome editing, which enables to carry out precise and specific genetic modifications in the DNA strands or generate genomic rearrangements to improve characteristics such as disease resistance and drought tolerance (Vasconcelos; Figueiredo, 2015).

Other areas related to the pre-production phase that will benefit from digital agriculture technologies are development and production of methods, equipment and inputs for laboratory analysis; chemical and biological inputs for managing the health and nutrition of plants and animals; seeds and seedlings; as well as financial services.

In the production phase, precision agriculture and robotics, supported by technologies such as remote sensing, geographic information system and monitoring of land use, enables the use of wireless sensors, located in the soil, in the plant, in the atmosphere or in machines and equipment, which together with data analysis software, enables more accurate field mapping. This mapping allows intelligent planting of seeds and optimized application of chemical or biological inputs for nutritional and sanitary crop management. Sensors that measure soil moisture indicate when irrigation is needed. Images of plants captured by cameras, drones and satellites can help detect pests, leading to the application of specific and adequate amount of pesticides. Devices can capture harvest information and map the productivity of each part of the land. Sensors embedded in agricultural machines can indicate the need for maintenance. Equipment installed in silos can indicate the storage conditions, avoiding storage losses. Sensors inserted in animals can help monitor their health, well-being and stress and predict calving dates, aimed at managing and improving performance.

In the context of digital agriculture, the production phase shows the emergence of digital farms or smart farms (Pivoto et al., 2018). On these farms, the agricultural establishment will be massively connected, monitored and automated in a fully integrated infrastructure, as illustrated in Figure 4. Through precision agriculture, sensors distributed throughout the property and interconnected to the internet (internet of things) will generate large volumes of data (Big Data) that will have to be filtered, stored (cloud computing) and analyzed. The human workforce will not be able to manage this amount of data and will count on algorithms further improved by computational intelligence techniques (analytics). After the analysis, the cycle will be closed by remote commands to tractors and agricultural implements, which, equipped with a global positioning system (GPS), will make specific interventions only when necessary to optimize cost, production and environmental impact. Society, through social networks, will be able to obtain detailed information about the production process, impacts and nutritional properties on their mobile devices. On smart farms, the current concept of precision farming is enhanced by context, situation and location recognition, data-rich ICT services, data integration, data communication,

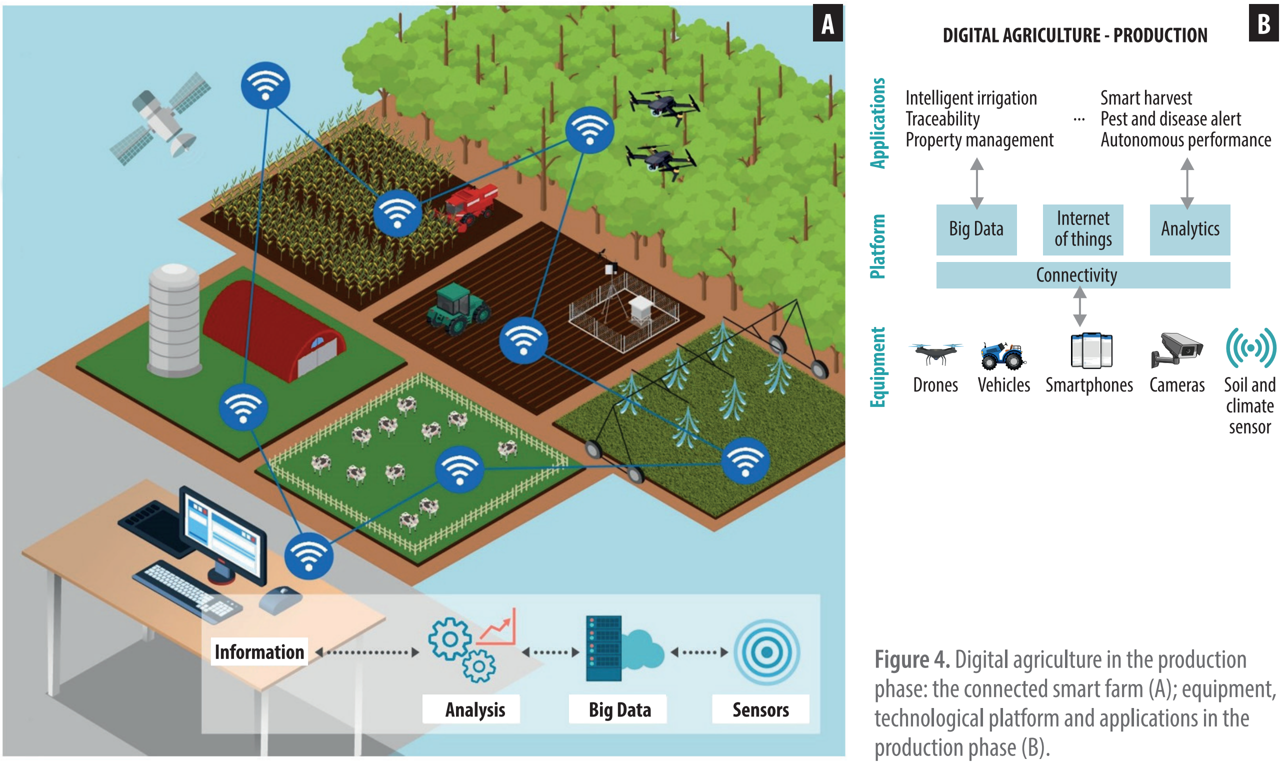

Figure 4. Digital agriculture in the production phase: the connected smart farm (A); equipment, technological platform and applications in the production phase (B).

standardization, signal processing and automation technologies, in addition to high-level automation planning and control (Sorensen, 2020).

In the post-production phase, new technologies will provide highly integrated communication and automation in the most varied activities of the agri-food and agro-industrial sectors. Prediction systems will forecast agricultural harvests and the risks involved. Advanced monitoring and control systems will inform consumers about food safety and sustainability. Traceability systems will provide production flow monitoring from the farm to the distribution centers, avoiding losses. Market information and economic variations will be processed and will guide the marketing processes. Storage, infrastructure and logistics will become more efficient, in addition to marketplaces, which will enable virtual connection between various actors in the production chains, offering negotiation and sales solutions. Packaging, environment and recycling, online restaurants and consulting are other areas that will be impacted.

In the context of digital agriculture, the data collection and management stage, through precision agriculture technologies, the internet of things and telematics, with the ensuing cloud storage, is expressed as Agriculture 4.0. Once the data is stored in the cloud, large analysis capacity is required, using artificial intelligence tools to process the large volume and extract relevant knowledge that not only helps decision making in property and production management but also conducts the performance of autonomous machines in the field (Saiz-Rubio; Rovira-Más, 2020).

The ability to use digital technologies to convert accurate data into knowledge to support and drive farmers' complex decision-making processes along the value chain will enable moving from precision farming to decision farming (Shepherd et al., 2018). The use of artificial intelligence and autonomous agricultural robots for agricultural work leads to a new phase, which is Agriculture 5.0 (European Agricultural Machinery Association, 2017). As the robots operate from the ground, the distance between the sensors and the target decreases to less than 2 m, increasing the accuracy of the captured data and allowing, for example, recording light intensity, moisture content of the soil, of the plant and the atmosphere and of disease severity, which will lead to a more specific action for the needs of each plant or animal (Saiz-Rubio; Rovira-Más, 2020).

In addition to including technological innovations, Agriculture 5.0 also needs to encompass characteristics such as: a) enable the production of more food on less land area and with fewer inputs; b) promote public policies and strategies to address the social and political aspects of agricultural systems; and c) contribute to reducing food losses along production and supply chains, including post-harvest losses and global food waste per capita in retail and consumption, besides it helping to understand consumer needs and their diets, in order to mitigate the impact related to the use of natural resources and the environment (Fraser; Campbell, 2019).

Brazil is already in tune with digital transformation in agriculture, especially through the incorporation of automation processes. Precision practices and processes, extensive use of sensors and sophisticated forecasting mechanisms and responding to climate change, for example, are among the improvements incorporated, opening spaces for Brazil in the global market, in strategic agricultural and bioeconomy sectors. The use of GPS-guided intelligent machines for planting, crop treatments and precision harvesting is growing in the country's most advanced production areas, with input savings, productivity gains and sustainability.

Initiatives for digital agriculture

Throughout its history, Embrapa Digital Agriculture has followed the evolution of ICT for the development of its applications, according to Figure 5. In the first phase, the systems were built as single-users and the software installed would run independently on desktop computers. It was when commercial internet was just beginning, and the main research centers and universities started connecting to the internet. In this phase, research had to adapt the existing models and solutions to the needs of Brazilian agriculture.

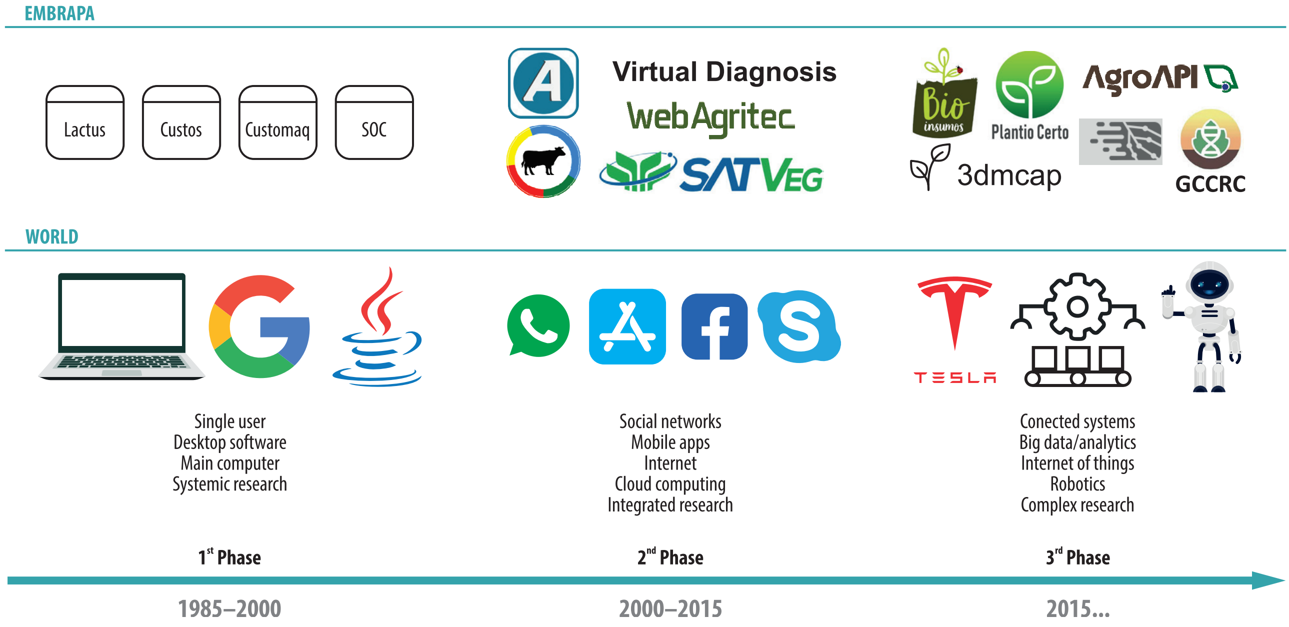

Figure 5. The evolution of Information and Communication Technologies and Embrapa's performance.

The second phase witnessed the appearance of mobile internet, which enabled using agricultural applications on cell phones, with data stored in clouds and social networks gaining global dimensions. Consequently, research gained an integrated dimension, since multidisciplinarity leads to aggregated solutions.

The third phase includes digital transformation, with highly automated agricultural activity through the constant evolution of precision agriculture and livestock systems, which are connected with all links in the production chain. The RD&I area will generate significant demands for new technologies in Brazilian agriculture. Some of the latest ICT innovations promise to leverage agricultural research. ICTs constitute the third pillar of scientific investigation, together with theory and experimentation, which allow simulating models of complex phenomena that could not be replicated in a laboratory. Mobile devices, cloud computing, Big Data, predictive analytics, wearable computing, cognitive computing, intelligent software systems, internet of things, advanced robotics, nanotechnology, biotechnology, integration of the omics sciences and the next generation genomics constitute the disruptive technologies that are transforming the way people live and work, through a new infrastructure in which the physical and digital worlds are fully interconnected.

In this scenario, in order to promote the sustainable and competitive development of the Brazilian economy, the National Plan for the Internet of Things was instituted by Decree no. 9,854, of June 25, 2019. This is an initiative of the Ministry of Science, Technology and Innovation (MCTI), the Ministry of Economy and the Brazilian Development Bank (BNDES), together with civil society – companies, academia, funding agencies and other bodies – to ensure that Brazil benefits from IoT technology. The plan defined four priority areas: industry, health, smart cities, and agriculture.

The potential impact and relevance of IoT for the country can be evidenced in its proposals, such as supporting pilot projects in these prioritized environments. In the rural area, it emphases initiatives such as "Tropical Farm 4.0", which increase the productivity and quality of Brazilian rural production by using data that, for example, help to accurately monitor biological assets (Produto 7C, 2017).

Within the scope of the National IoT Plan, the Agro 4.0 Chamber (Câmara Agro 4.0) was created as a technical cooperation agreement between the MCTI and the Ministry of Agriculture, Livestock and Supply (MAPA). The idea is to have a discussion group with the participation of government, companies and academia to build a strategy for connected farms that use solutions such as automation, interactivity, real-time monitoring, Big Data, among others. One of its actions is to promote connectivity in the countryside by expanding broadband internet in the rural environment. The Agro 4.0 Chamber is coordinated by the MCTI and the MAPA and the participation of actors from the private sector, academia and research institutes to debate and present solutions in the following areas: i) Development, Technology and Innovation; ii) Professional Development; iii) Productive Chains and Supplier Development; and iv) Field Connectivity.

To enable implementing the actions from the National IoT Plan, several development activities were created. In 2018, the BNDES Public Notice for IoT Pilots - Internet of Things was launched to finance project proposals for the implementation of pilots focused on the development of integrated IoT solutions through tests in real and controlled environments, whose impacts can be evaluated to allow its massification, commercial viability and interoperability.

Another initiative to promote digital transformation in the country is the applied research centers in artificial intelligence (AI), which will be created through cooperation between the MCTI, the São Paulo Research Foundation (FAPESP) and the Brazilian Internet Steering Committee (CGI.br). These centers will commit to the development of scientific, technological and innovation research, applied and oriented to problem solving through AI. The first four centers, two in São Paulo and two in other states, will focus on health, agriculture, industry and smart cities. The centers will be supported for 5 years and renewed for more 5 years depending on the results achieved (Arantes, 2019).

Along the same line, the Association for the Promotion of Brazilian Software Excellence (Associação para Promoção da Excelência do Software Brasileiro – SOFTEX), responsible for the Softex Priority Program of the Secretariat of Entrepreneurship and Innovation of the MCTI, launched the Softex Notice no. 01/2020 – Notice for Qualification of Institutions to Support the Research Process, Development, Innovation and Acceleration of IA²MCTIC Projects. The purpose of the Notice was to select and qualify pairs of Science and Technology Institutions (ICTs) and accelerators for joint action in the IA²MCTIC Program. The consortium formed by Baita Aceleradora, Eldorado Institute and Embrapa Digital Agriculture, was one of those certified in this initiative.

Embrapa, whose mission is to create research, development and innovation solutions to ensure the sustainability of agriculture, for the benefit of Brazilian society, is a protagonist in the technological modernization of agriculture. In the late 1990s, it created Embrapa's Precision Agriculture Network (PA Network) to provide guidance on the best and most appropriate use of PA and for research and development of new technologies. It currently involves 20 company research centers and more than 50 partners, such as companies, research institutions, universities and rural producers. The PA Network has the National Reference Laboratory for Precision Agriculture (LANAPRE), installed at Embrapa Instrumentation, in São Carlos, São Paulo state. The space, in a single location, is used to research and develop equipment, sensors, mechanical components and on-board electronics (Embrapa, 2020b).

Aware of the need to follow the global and national trends of the new economy and the world order and how these transformations impact agriculture, Embrapa, through its Strategic Intelligence System (Agropensa), prepared the document *Vision 2030: the future of brazilian agriculture* (Embrapa, 2018). In this process, the company and its network of partners prospected and analyzed the challenges and signs of new directions. These assessments gave rise to a group of seven megatrends: Socioeconomic and Spatial Changes in Agriculture; Intensification and Sustainability of Agricultural Production Systems; Climate Change; Risks in Agriculture; Adding Value in Agricultural Productive Chains; Consumer Protagonism; and Convergence of Technology and Knowledge in Agriculture. These integrated megatrends signal the agricultural challenges for the country.

Supported by the demands, opportunities and megatrends raised in Agropensa, in 2018, Embrapa created its project portfolios that set the challenges to direct its research focus. There are currently 33 portfolios, totaling 330 innovation challenges focused on various areas of agriculture, livestock, commodities and food production, as well as automation, precision and digital agriculture, climate change, biotechnology, nanotechnology and intelligence, territorial management and monitoring. In particular, the goal of Automation, Precision and Digital Agriculture Portfolio is to plan, promote and monitor the processes of development, adaptation and dissemination of knowledge and technologies in automation, precision agriculture and digital agriculture to increase productivity and sustainability of production systems. Moreover, it will provide support for generating assets that add value to agricultural products and processes. Through this portfolio, the company seeks to promote research that will contribute to the digital transformation of Brazilian agriculture.

Also within the scope of digital transformation in agriculture, the agricultural startups, the AgTechs, which are innovative technology-based firms focused on developing digital applications in agriculture. AgTechs play an important role in the implementation of digital agriculture in Brazil. According to the 2nd AgTech Census – Startups Brazil, carried out by AgTechGarage, the largest investments made by AgTechs are in the development of solutions for soy (46%), corn (41%), beef cattle (30%), sugar cane (35%), coffee (25%) dairy cattle (20%), citrus (18%), forestry (15%), fish (11%), swine (10%) and poultry (10%). In addition to these, there are also solutions for horticulture, fruit farming, cotton, organic and agroecological agriculture and equine production (Agtechgarage, 2020). In the study of Radar AgTech Brazil 2019: Mapping of Startups in the Brazilian Agro Industry, carried out in partnership with SP Ventures, Homo Ludens and Embrapa, within the Bridges for Innovation Program (Pontes para Inovação), it was found that there are currently a total of 1,125 startups related to agriculture in Brazil, with 196 in the pre-production phase, 397 in the production phase and 532 in the post-production phase (Dias et al., 2019). This number only tends to grow, given the importance of agribusiness for the Brazilian trade balance and the need to modernize and use new digital technologies so that the sector maintains its strength in the country's economy and in the global food supply.

Incorporating megatrends in agriculture: innovation ecosystem for digital agriculture

Reducing risk and vulnerability in agriculture and agricultural business, as well as increasing their resilience and adaptation to the new conditions imposed by climate change, are completely dependent on a structure for organizing and processing data and information, based on powerful computational platforms, generating knowledge for field management and public and private decision-making. The Digital Agriculture Innovation Ecosystem and its connected research institutions will have a powerful tool to support decision-making and propose public policies that involve all agents in the production chain, including the final consumer. It is essential for federal, state and municipal governments to meet both rural and consumption demands throughout the country. This collaborative environment, illustrated in Figure 6, will also enable solutions for research programs related to bioeconomy, biotechnology and climatology, facilitating the transformation of these research results into products and technologies for the agricultural sector. This, in turn, can generate new demands, feeding back into the process of research, development and innovation ecosystem.

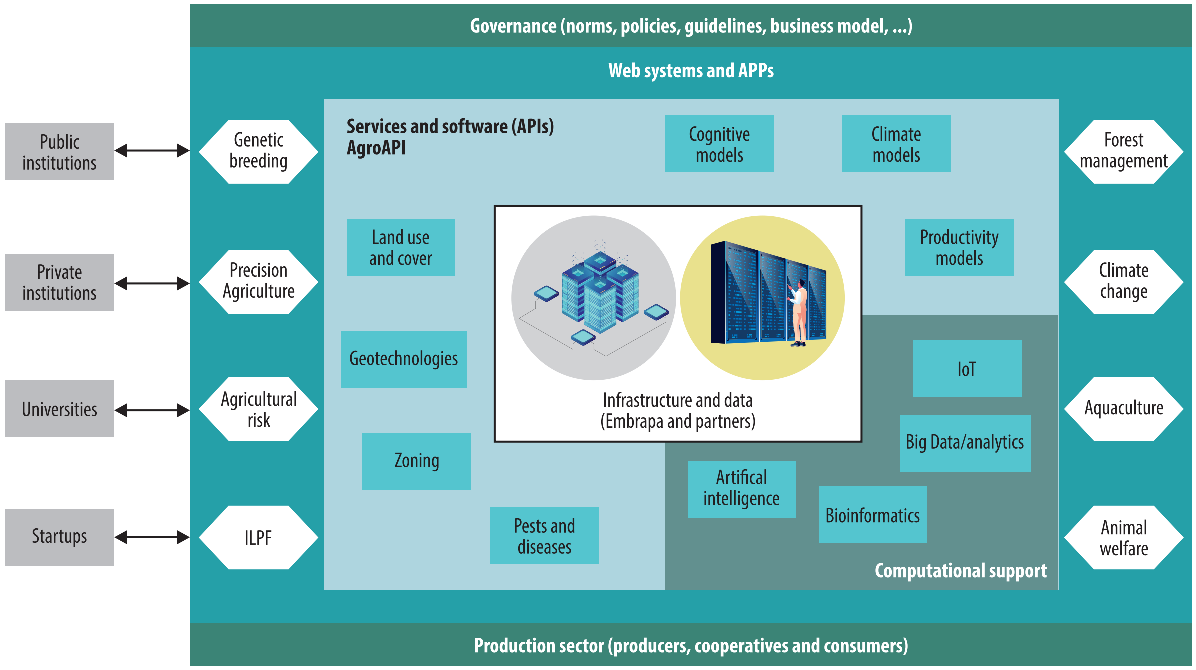

Figure 6. Innovation Ecosystem for Digital Agriculture.

Embrapa proposes and participates in this new Digital Agriculture Innovation Ecosystem, which is focused on the contribution of new disruptive technologies to add value to production, increase farmers profitability and food security. This reality imposes new challenges on entities linked to the sector, such as Embrapa, which must progressively act in cooperation, sharing expertise and knowledge for the development of new solutions, technologies and businesses. As a public research corporation, Embrapa can play a facilitating role in this environment of open innovation, bridging the gap between its various actors, which include rural producers, the public sector, research institutions, startups and companies in the ICT area and in the agricultural sector. In this ecosystem, Embrapa is ready to offer services and knowledge that can be shared by the entire agribusiness with a view to digital transformation in agriculture.

In the context of digital agriculture, which generates immense data and information, Embrapa proposes to implement a high-performance computational infrastructure (Data Center). This will provide support to improve the generation of relevant knowledge for the national agricultural policy and the integrated public and private risk management of agribusiness for the sustainable development of agriculture in Brazil. The new Data Center will have high capacity to store, organize and process data to generate information and knowledge that meets the demands of Agriculture 4.0. It will also allow the offer of three types of services: infrastructure, platform and software.

In the infrastructure service, Embrapa's partners will be able to use the managing services of large data volumes securely, including storage, high-performance processing, memory capacity and backup services for the data generated in their research.

In the software service, it will be possible to access several applications developed by Embrapa, such as Agrometeorological Monitoring System (Agritempo) (Agritempo, 2020), Agricultural Planning and Monitoring System (Webagritec) (Massruhá et al., 2008), Temporal Vegetation Analysis System (Satveg) (SATVeg, 2020), among others. Applications that can be developed both by Embrapa and its partners will be available. With regard to Embrapa, several applications related to the availability of information on bio-inputs, management of dairy farms, measurement of greenhouse gas emissions, production cost, indication of the best time to plant crops, provision of agrometeorological information for municipalities and Brazilian states, cattle production management, among others, are available at Embrapa's app store, both on Google Play and on Apple App Store.

In the platform service, Embrapa is already making available a pioneering tool in Brazil to serve the market of digital agriculture technologies called the AgroAPI platform (Vaz et al., 2017; Agroapi, 2020). AgroAPI provides information and models that can be used by companies and startups to create software, web systems and mobile applications for the agricultural sector, with lower cost and time reduction. The technology also enables an interface with mobile devices and embedded equipment that may emerge with the growth of the internet of things, which is fundamental for the digital transformation in rural areas. The AgroAPI platform will allow creating a supply and demand network for shared services that will benefit research networks and institutions in Brazil such as universities, startups, public and private institutions, since the data will be stored securely, and shared according to the interests of each institution. All these institutions can both consume the stored data and systems or make available the data and systems produced by them. In this initiative, the experimental fields of Embrapa Research Centers will act as testbeds to carry out experiments with disruptive technologies in the field, in partnerships with the public or private sector, working as showcases to demonstrate the implementation of digital agriculture.

Producers, cooperatives, farmers and technology and transformation companies will benefit from this entire infrastructure, as they will have access to vast aggregated, analyzed, and available information that will help their decision-making.

By developing collaborative work within the Digital Agriculture Innovation Ecosystem, Embrapa will work together with Unicamp's International Hub for Sustainable Development (HIDS) (Hub Internacional para o Desenvolvimento Sustentável, 2020). It focus on digital agriculture for the development and sharing of services for users of the agricultural production sector in the state of São Paulo, with the support of the municipality of Campinas and the state government. HIDS' vision is to contribute to the sustainable development process, aggregating national and international efforts to produce knowledge, innovative technologies and education for future generations, mitigating and overcoming the social, economic and environmental fragilities of contemporary society.

In this ecosystem, Embrapa Research Centers work on development and innovation focused on agriculture (agricultural, livestock, forestry and agro-industrial activities) and on the environment, integrating the demands of production systems with the needs for the conservation of natural resources and environmental preservation. Its research generates significant impact on public policies such as the Agricultural Climate Risk Zoning (ZARC), the Low Carbon Agriculture Plan (ABC Plan), the National Network for Research and Environmental Monitoring of Aquaculture in Union waters (Network) and the National Inventories of Agricultural and Waste Emissions. In addition to these, it is also involved in the preparation of Life Cycle inventories, which support environmental performance assessments in the different production chains that are important to Brazil, such as sugar-energy, as a result of the National Biofuels Policy (RenovaBio). In addition, Embrapa will be able to provide shared infrastructure of important multiuser laboratories, such as the Multiuser Bioinformatics Laboratory (LMB), the National Reference Laboratory of Precision Agriculture (Lanapre), the National Laboratory of Nanotechnology for Agribusiness (LNNA), the Multiuser Laboratory of Spectroradiometry, the Multiuser Laboratory of Chemistry of Natural Products (LMQPN), the Multiuser Laboratory of Biosafety for Livestock (BIOPEC), the Multiuser Laboratory of Molecular Biology (LMBM), the Sustainable System Analysis Laboratory (LASS) and the Multiuser Complex of Livestock Bio-efficiency and Sustainability (CMB), comprising four laboratories: Livestock Metabolism and Environmental Impacts, Biotechnology and Environment, Precision Livestock and Animal Health.

Another Embrapa contribution is the availability of experimental field structures that enable digital transformation in the field, through remote data collection, as well as management and decision-making, made possible by the interaction of electronically identified animals, equipment, actuators and sensors.

This experimentation structure will allow generating research data, for example in: 1) integrated systems (crop-livestock-forest integration, crop-livestock integration, livestock-forest integration); 2) milk production, milk quality and milk composition; 3) zootechnical data; 4) animal behavior; 5) physiological parameters; 6) animal consumption; 7) greenhouse gas emissions; and 8) edaphoclimatic data. Other expected deliverables are the development of applications for mobile devices for real-time monitoring, management and decision-making, and the development of digital platforms for information sharing and access to Embrapa's Spatial Data Infrastructure (Geoinfo) (Geoinfo, 2020). The spatial data can be related to Land Mapping, Agricultural Aptitude Zoning, Ecological-Economic Zoning, Land Use and Coverage Mapping and Monitoring, Land Use and Occupation Monitoring, Relief Data and Climatic Data.

This entire ecosystem will be governed by standards, policies and business models agreed between the partners and in accordance with the guidelines established by the federal government.

Final considerations

Brazil is one of the largest agricultural producers and exporters in the world, and the country needs to guarantee and expand its production capacity with sustainability while meeting the global demand for food and nutrition security. As a major exporter of agricultural commodities, modernization and innovation are needed throughout the agricultural production chain, thus converging to digital agriculture as a result of the digital transformation in the sector.

This work presented an overview of the evolution of ICT in agriculture and how digital transformation is driving the fourth industrial revolution and the emergence of Industry 4.0. Currently, this is inspiring the implementation of new technologies in digital agriculture and the consequent emergence of Agriculture 4.0 towards Agriculture 5.0.

Despite the growing interest and effort in implementing digital agriculture, there are challenges to be overcome, such as the difficulty in coordinating actions involving the various institutions and the business models to be practiced. In addition, the industry faces the lack and necessary amount of trained human resources; the need to guarantee information security; the definition of ownership when dealing with the generated data and information, as well as issues of data integration from different formats or different sources.

In this scope, some strategies for the full achievement of digital agriculture are conceptualized, such as: address the definition of rights and ownership of data; encourage the use of open standards protocols for data interoperability and communication between equipment; improve connectivity and broadband coverage for cell phones and the internet in rural areas. We also need to encourage research in order to support intelligent applications in agriculture, and lastly, we need to establish alliances between the public and private sectors to define strategies and policies for the implementation of digital agriculture in a collaborative way.

The challenges presented with the transformation of agricultural data, notably in relation to the digitization, digital collaboration, and sustainable development, make Embrapa one of the driving institutions in the implementation of digital agriculture in the country. One of the concrete initiatives to address these challenges is the creation of the Digital Agriculture Innovation Ecosystem, where Embrapa pursues the integration of the various segments and sectors by acting as a facilitator between companies interested in developing collaborative work.

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