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Challenges, trends and opportunities in digital agriculture in Brazil

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Introduction

The combination of soil conditions, climate, relief, science, technology, public policies and the agricultural entrepreneurship made Brazil one of the world leaders in agricultural production and export. Recent forecasts by the Ministry of Agriculture, Livestock and Supply (Brazil, 2019b) indicate that grain production could surpass the current level of 250 million tons, reaching between 300 and 350 million tons in the 2028/2029 crop-year. As for meat production (chicken, pork and beef), projections indicate going from the current 26 million to 33 million tons by the end of the next decade. There is also a growing demand for cotton, cellulose, milk, sugar and fruits, especially mango, grape and apple. The domestic market and international demand are indicated as the main growth factors for most of these products.

The growth of this production should continue based on productivity. Total factor productivity (TFP) has grown on average 3.50% per year over the past few years, and is forecasted to grow at 2.92% per year for the next decade (Gasques et al., 2016). Embrapa (2018) also highlights the importance of Brazilian agricultural intensification in the coming years, with emphasis on multiple crops per year in the same area, recovery of degraded pastures, precision irrigation and more sustainable use of inputs and natural resources. In turn, population growth, continued urbanization, longer life expectancy, changes in dietary patterns and economic power are the driving factors of greater global demand for food, energy and water.

Digital technologies can help solve this complex equation with countless economic, social and environmental variables, which require producing more food, with quality and with less use of natural resources. Digital agriculture, also called "4.0", comprises technologies, which are already operational or under development, such as robotics, nanotechnology, synthetic protein, cellular agriculture, gene editing technology, artificial intelligence, blockchain and machine learning. These technologies can have widespread transformative effects for future development of agriculture and agrifood systems (Klerkxa; Roseb, 2020).

Bolfe and Massruhá (2020) point out that the process of digital transformation in rural properties is no longer an option, it is an essential path to make Brazilian agriculture more competitive and with greater added value. This transformation is understood as interdisciplinary and transversal, not limited to regions, crops or social class. Its potential benefits amplify innovations and interaction between links in agricultural production chains, promoting new approaches and applications for input manufacturers, rural producers, processors, distributors and consumers (Figure 1).

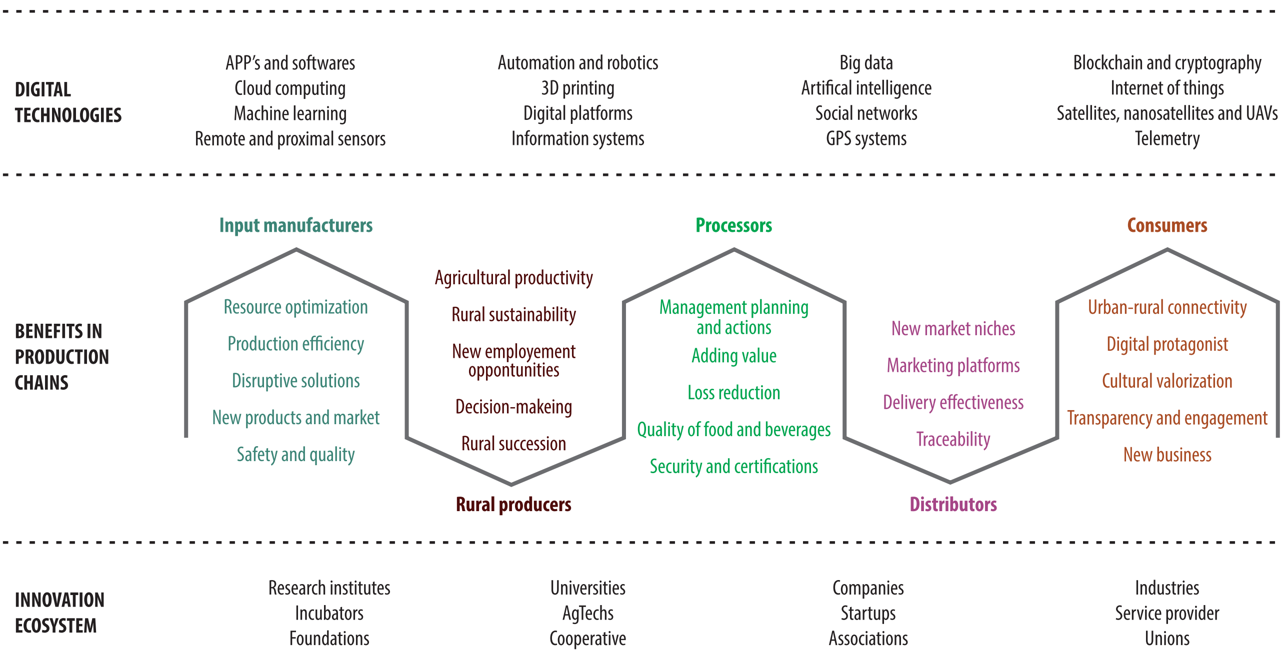

Figure 1. Potential benefits of digital transformation in agricultural production chains.

Source: Bolfe and Massruhá (2020).

This digital transformation environment also shapes development agendas at various scales. Internationally, it can be associated with the 2030 Agenda, which includes 17 Sustainable Development Goals (SDGs) (United Nations, 2015). In this context, the digital transformation in agriculture can also significantly contribute to achieving these goals, particularly in reducing hunger, health and well-being, decent employment and economic growth, reducing inequalities, responsible consumption and production, combating climate change, life on earth, peace, justice and strong institutions.

Estimates by the UNGC (United Nations Global Compact, 2017) indicate that the world market for digital agriculture, in 2021, will be worth 15 billion dollars, and that 80% of companies expect to have competitive advantages in this sector. However, recent international aspects involving trade and health issues between the United States and China, as regards the Covid-19 pandemic (United Nations, 2020), generate an environment of uncertainty to some degree, but with greater expectations of potential growth in the use of digital technologies in agriculture as of 2020.

In this context, this chapter lists some of the main scientific, technological, social and economic challenges and, subsequently, points out trends and opportunities for the future of Brazilian agriculture.

Scientific and technological challenges

Digital online services

The offer of online digital services to rural producers gained momentum in the early 2010s and has expanded since then. With the widespread use of smartphones, most of those services migrated to this platform (Duncombe, 2016). Many technology startups applied to agriculture (AgTechs) that have emerged in recent years have wagered on this type of technology. As it is still relatively new, how to best offer this type of product is still being defined, but this technology is already a reality, and most of the technologies mentioned in this section are or will be incorporated into portfolios of already existing digital services or under development. The challenges that still need to be overcome concern aspects that are not necessarily technological, such as ownership of the data generated by this type of tool, lack of synchronization between the needs of producers and the information generated by the tools, and data security (Rotz et al., 2019). Regardless of what solutions will be implemented for these problems, new digital service platforms will continue to be developed, many of them based on the technologies discussed as follows.

Management and monitoring of plant production

There are several factors that need to be constantly monitored in agricultural management, for instance production, productivity, presence of diseases, pests, weeds, nutritional deficiencies, water stress, among others. One of the main challenges regards monitoring stress, which can be divided into three stages: stress detection, determining the cause of the stress and solving the problem. Despite recent innovations in artificial intelligence, the process as a whole is still mostly manual. However, the degree of automation has increased, and several companies (startups in particular) already offer services in this regard (Wolfert et al., 2017).

A large number of mathematical models have been developed to process different variables and provide indications regarding crop susceptibility to stress-inducing events. For example, data on precipitation, moisture and leaf wetness can be used to calculate the probability of incidence of certain diseases. These models have been improved and fed with increasingly higher quality data, making them a fundamental part of the integrated management of rural properties. However, for effective stress management, it requires detecting them directly in the field. The challenge is to achieve this detection early enough to avoid significant damage. Although there are proximal methods for stress detection, the trend is to make use of these remotely obtained images much more. In the short and medium term, drones will likely dominate this activity due to the high temporal resolution of these images, enabling to detect problems even in individual leaves (Barbedo, 2019a). As more sophisticated sensors are embedded in satellites, they will likely gain attention, mainly due to their wide-ranging coverage.

Conventional cameras (RGB) have limited ability to detect early stresses, as they cannot go beyond human visual capacity. Therefore, it is vital to have sensors that can capture other spectrum bands besides the visible one, such as multispectral and hyperspectral cameras. Multispectral cameras, which typically include three to five spectral bands, are increasingly being used. However, the falling costs and miniaturization of hyperspectral cameras, which separately capture hundreds of spectral bands, will make them an especially attractive alternative in the near future. (Thomas et al., 2018).

Once stress is detected, it is necessary to determine its cause in order to take appropriate actions. Under certain conditions, current sensors can provide sufficient information so that models based on artificial intelligence can provide a reliable classification for the problem being observed (Barbedo, 2018, 2019b), but in most cases it requires that a specialist should do this identification, or it should be done through laboratory analyses. The problem is that different types of stress often produce similar visual signals (Barbedo, 2019b). The spectral profiles produced by different agents tend to differ to a greater degree, but even using sensitive hyperspectral sensors the confusion index is high (Thomas et al., 2018). In the future, the trend is to combine imaging with other sources of information (meteorological variables, management history of the property, soil characteristics, etc.) to increase the degree of automation of the process, although the complete elimination of manual activities is unlikely in the near future. In addition to identifying stress, in many cases it is also important to determine the severity of symptoms so as to deal with the problem. Although there are several algorithms for this purpose, many of the difficulties mentioned are also applicable in this case (Bock et al., 2020).

After locating and identifying the stress, it is necessary to act to eliminate the problem. In many cases, it is necessary to apply products such as pesticides and nutrients. Autonomous vehicles have been developed by several research groups so that this activity can be carried out not only without the need for permanent human supervision, but also at the location and in the necessary quantity, reducing costs and environmental impacts (Reina, 2016). In the near future, it will be possible to have one or more of these vehicles monitoring and operating within the property. In parallel, actuators can also be installed on agricultural machinery to carry out these same activities.

It is noteworthy that artificial intelligence algorithms have been used in other applications, such as crop prediction, location of fault lines, determination of production quality, determination of the degree of ripeness of fruits/grains, among others (Liakos et al., 2019). The trend that is being observed is that tools based on artificial intelligence and machine learning will continue to gain space and will be part of the routine of most properties in the near future.

Management and monitoring of animal production

Appropriate management of livestock farms has evolved considerably in recent years, especially in the case of dairy and beef cattle in the intensive system. However, farm management implementing the extensive production system still faces significant challenges (Barbedo; Koenigkan, 2018). More effective control of the variables involved in property management is essential to maximize profits and reduce the number and severity of problems. Two alternatives have been used, albeit in a limited way, for monitoring large animal husbandry properties: sensors attached to the animals and drones for remote monitoring (Barbedo; Koenigkan, 2018).

Sensors can be attached to animals through ear tags or collar tags, which can collect different information about these animals, including location, temperature and patterns of movement and chewing (Rahman et al., 2018). This information allows to detect potential problems, such as diseases, and infer various aspects of animal behavior, which is important, for example, to create effective mechanisms to accelerate fattening and define the optimal slaughter point (Miller et al., 2019). For the data to be collected at the required frequency, there needs to be effective communication between the individual sensors and the data processing center. Receivers can be installed on poles distributed throughout the property, or data can be collected by drones flying over the animals (Barbedo et al., 2019). Both options have limitations in the case of large properties: in the case of fixed receivers, it would require installing numerous receivers, which represents a high initial cost, in addition to the difficulty of maintaining equipment located in more distant regions. As for drones, in addition to their limited autonomy, the planning of flights must be careful so as to include all animals. There are already commercial solutions offering monitoring through individual animal sensors, as shown in simple internet searches. However, such solutions are not suitable for all types of properties, and the costs are still high. It is noteworthy that technology costs tend to fall as their use increases.

The use of drones for imaging animals is more recent, and the practical use of this type of technology still depends on more research efforts and on the development of new algorithms. There are several efforts in this direction (Barbedo et al., 2019, 2020), since, once made available, this type of technology has several advantages: it does not need specific infrastructure, it is a comparatively cheaper option, several types of sensors can be embedded in drones (RGB, thermal, multispectral, hyperspectral cameras), in addition to the potential of providing other types of information in addition to that which can be obtained with ear tags. There are ongoing studies that, based on animal measurements obtained using the captured images, are focused on estimating the weight of each animal without having to use a scale. Other information that may be obtained in the future using drones include the number of animals in a given area, and the detection of anomalous events such as disease and calf births. However, there are still some limitations that need to be overcome, such as the relatively short autonomy of current UAVs and the difficulty of identifying individual animals when they are grouped together (Barbedo et al., 2020). In the case of autonomy limitation, possible future solutions include the use of images captured at an angle to cover larger areas (Barbedo et al., 2020) and the development of new drones with greater autonomy, such as the "balloon drone". As new solutions emerge, the use of drones in livestock is expected to grow substantially in the near future.

It is also important to mention the use of satellites. Although the spatial resolution of images captured by satellite is not yet sufficient to allow its effective use in monitoring herds, advances in imaging technology and the multiplication of micro and nano-satellite constellations with specific purposes tend to make the use of this type of equipment viable in the future. This does not mean that this technology will replace the others, but it will be an additional alternative that will certainly be beneficial under certain conditions.

Databases in agriculture

The evolution observed over the last two decades in relation to machine learning techniques has made most detection, recognition and classification problems treatable, potentially leading to developing tools of great practical use. However, for such tools to be reliable and robust, the database used to produce the models should be representative of all the variability found in practice (Barbedo, 2018). In most cases, this involves collecting a large number of samples, such as images, measurements or analyses. In the case of images, for example, there are situations that require collecting hundreds of thousands of samples (Barbedo, 2018). The challenge is even greater when the samples need to be properly annotated, that is, information about what is represented in that sample, where the sample was collected, and additional information needs to be correctly generated so as to correctly infer the model. As a result, it is often impossible for a single research group to be able to build a truly representative database (Barbedo, 2019b).

There are two alternatives that have been applied in some circumstances and that will likely prevail in the future. The first is citizen science (Irwin, 2002). This approach, which is mentioned in the 2030 Agriculture Vision document (Embrapa, 2018a), makes use of non-professional volunteers to collect data as part of scientific research, particularly in ecology and environmental science (Silvertown, 2009). In the case of plant disease detection, for example, producers and rural workers could collect images of symptoms in the field and, after they are sent to a server, these images could be labeled by phytopathologists. As mobile devices with imaging capabilities become ubiquitous, the challenge will be to find mechanisms to promote volunteer participation (Barbedo, 2019b).

The second alternative that could prevail in the future is that of sharing the generated databases (Barbedo, 2018). Most technological and scientific challenges are addressed simultaneously by several research groups, each generating its own dataset. If such databases were made available and integrated, the resulting set would likely be much more representative and applicable to real world conditions. Embrapa has been contributing to this type of efforts through the availability of databases such as Digipathos (Embrapa, 2019), one of the first to be part of the Network of Scientific Data Repositories of the State of São Paulo (Fundação de Amparo à Pesquisa do Estado de São Paulo, 2019). A complementary step for adding value to databases is adherence to the findable, accessible, interoperable and reusable (FAIR) principles, which dictate the findability, accessibility, interoperability and reusability standards (Wilkinson et al., 2016).

Socioeconomic challenges

Connectivity in the field

Brazil is among the top ten world markets for mobile telecommunications and fixed broadband data (Agência Nacional de Telecomunicações, 2020). The 2017 agricultural census indicated that internet access grew by 1,900% compared to 2006, which is accessed by around 30% of rural producers (1.43 million in 2017), 659,000 via broadband and 909,000 via mobile internet (IBGE, 2017). Despite representing a relatively high increase, these data indicate that approximately 3.5 million rural establishments – that is, 70% – did not have access to the internet. A study with 750 Brazilian farmers indicates that 47% use at least one tool in precision agriculture, while 33% use two or more, and the young profile of Brazilian rural producers less than 45 years old for some regions and production systems, is one of the reasons for this receptivity to new technologies (Mckinsey Consultoria, 2020).

Even with recent investments by the public and private sectors, the lack of connectivity in rural areas is still one of the main challenges for the insertion of agriculture in the digital transformation process. Territorial dimensions, the low demographic density of a large part of the rural area and socioeconomic inequalities are some of the main obstacles to increasing the availability of internet access in the country. The National Bank for Economic and Social Development (BNDES) (Banco Nacional de Desenvolvimento Econômico e Social, 2017) estimates that greater connectivity in agriculture through the internet of things (IoT) could generate between 50 and 200 billion dollars of annual economic impact in 2025. It is also highlighted that standardization and interoperability of the components of IoT solutions should be sought in order to achieve a greater scale of adoption, faster development of new services and applications, thus fostering the capacity for innovation.

Connectivity is essential to improve technical assistance, distance education, access to market information, the use of management software and applications, and the integration of agricultural machinery and equipment, reducing production costs and improving farm productivity. The Research Foundation of the State of São Paulo (2020) emphasizes that connection infrastructure and data interoperability are the major obstacles to the inclusion of Brazilian agriculture in the 4.0 era, which should help the producer overcome the challenge of expanding the supply of food at affordable prices and in a sustainable way.

Private initiatives to increase internet access in rural properties via satellite, antenna network and bluetooth technologies are expanding in Brazil. An example is ConectarAgro (2020), which attempts to encourage and promote solutions for connectivity in rural areas through tower, radio and antenna technologies.

However, small and medium producers have greater difficulties due to implementation costs. Possible public resources to improve the internet infrastructure may originate from the proposed bill No. 172/2020 (Brazil, 2020a), which is being processed in the National Congress, aimed at modifying the General Telecommunications Law for access to the Fund for Universalization of Telecommunications Services (FUST). The proposed bill provides for the financing of infrastructure expansion in rural or urban regions with a low Human Development Index (HDI), encouraging the use and development of new connectivity technologies to promote economic and social development. Greater connectivity in rural areas is also highlighted in the National Internet of Things Plan (Brazil, 2019a) and in the discussions of the Agro 4.0 Chamber, which has a work group for the issue of Connectivity in the Field (Brazil, 2019a, 2020b).

Costs of digital technologies

Data from the IFAD (International Fund for Agricultural Development, 2020) indicate that around 63% of the poorest people in the world work in agriculture, with the vast majority in small rural properties. In Brazil, according to the Agricultural Census (IBGE, 2017), of the 5 million rural establishments, 4.5 million have an agricultural area of less than 100 ha, that is, they represent around 90% of rural producers. A survey carried out by Embrapa, Sebrae and Inpe (Bolfe et al., 2020) with 753 rural producers, companies and service providers in digital agriculture from all Brazilian regions detected that 67% of these farmers and 58% of service providers indicate that the main challenge for implementing and keeping digital transformation in the property is still investing in machines, equipment and/or applications. Thus, for a significant portion of rural producers, especially small and medium-sized ones, the digital transformation process is still perceived as difficult in view of the current perception of potential economic benefits.

On the other hand, a study estimated a relevant potential economic impact regarding the use of the main technologies in precision agriculture in Brazil for sugarcane, corn and soy products. It was observed that a scenario of 10% increase in the productivity of these crops, with or without a reduction or increase in fertilizers, could increase the GDP of the country's economy by around R$ 11 billion and generate more than 450 thousand jobs (Costa; Guilhoto, 2013). DeBoer (2019) analyzed precision agriculture for sustainability and emphasized that its applications increase the ability to identify the spatial variability within the field, using this information for a more targeted crop management, operating resources more efficiently, making agriculture more productive, sustainable, while reducing its environmental impact.

Another important trend facing the challenge of costs in digital agriculture is the free availability of public and private instruments and training. Some examples are the platforms and applications available that support the management of property and agricultural production, such as: WebAgritec, ZARC Plantio Certo, SatVeg, Agritempo, WebAmbiente, Roda da Reprodução, BioInsumos e AGro (Embrapa Informática Agropecuária, 2019a, 2019b, 2020a, 2020b); AFSoft, Siscob, Qualisolo (Embrapa Instrumentação, 2020); MapOrgânico, Geoweb Matopiba, GeoInfo (Embrapa Territorial, 2020); RenovaCalc, AgroTag e Aquisys (Embrapa Meio Ambiente, 2020).

Rural family succession

The 2017 Census of Agriculture indicated that of the total of five million agricultural producers, 15% declared that they had never attended school, 14% had literacy level, and 43%, had at most elementary education. Thus, 73% of all producers have, at most, elementary education as their education level – complete or partial. It is worth mentioning that 1.1 million producers (23%) declared not knowing how to read and write (IBGE, 2017).

Embrapa (2018), in its study on the future of Brazilian agriculture, points out that 91% of the population will be concentrated in urban areas in 2030. It also emphasizes that the development of technologies suited to different socioeconomic and environmental conditions is not enough to raise the Brazilian agricultural productivity and family income, since producers have a low level of education and lack access to technical assistance and rural extension, thus, incorporating technologies is difficult or even impossible. The study also highlights that the issues associated with income and the demographic depletion of the countryside are altering an important structural element of national agriculture, the hereditary succession in the command/management of properties.

Ownership and management are understood as two major dimensions in the family succession process, in which the digital technology factor is pointed out as one of the opportunities for future succession processes in Brazil (PWC Brasil, 2019). Thus, it is important to have actions to facilitate the succession decision-making process, especially for small and medium rural producers, regarding what should be produced and how this production will be carried out, generating information and assisting in the management of production adjusted to the reality of rural establishments.

Sustainable rural development

The great challenge of world agriculture is to raise its level of economic, social and environmental sustainability. Among the Brazilian goals proposed in the Sustainable Development Goals Agenda for 2030, "ending hunger, achieving food security and improving nutrition and promoting sustainable agriculture" is highlighted (Ipea, 2018). Specifically in agriculture, some of the challenges are to "ensure sustainable food production systems, through research policies, technical assistance and rural extension, among others, in order to implement resilient agricultural practices that increase production and productivity, while helping to protect, recover and conserve ecosystem services, strengthening the capacity to adapt to climate change, extreme weather conditions, droughts, floods and other disasters, progressively improving the quality of land, soil, water and air" and "increase agricultural productivity and income of small food producers, particularly women, family farmers, traditional peoples and communities, targeting both the production of self-consumption and guaranteeing the social reproduction of these populations, as well as their socioeconomic development."

According to the Ministry of Agriculture, Livestock and Supply (Brasil, 2019a), Brazilian agriculture has increased its total production in recent decades, and based on productivity, this growth should continue until 2030. One of the challenges is the need for greater integration of geotechnologies with new remote sensing image processing and fusion algorithms to raise the level and accuracy of real-time use of natural resources, further enhancing agricultural sustainability (Bolfe, 2019).

Among the innovation challenges, Embrapa (2019) points out the need for Brazilian agriculture to increase: a) the efficiency of water use in irrigated agricultural systems for grain, vegetables, fruit, pasture and sugarcane; b) the adaptive capacity and resilience of agricultural production systems with greater projected economic impact and relevance for food security based on climate change scenarios; c) the guidance of land use and occupation in land conversion and expansion areas of the agricultural frontier in the Cerrado, Caatinga and Amazon biomes. For Brazil to definitively assume the leading role in global sustainable agricultural production, it will need greater public and private investments in science, innovation, entrepreneurship, connectivity infrastructure, communication and professional training in digital agriculture (Bolfe; Massruhá, 2020).

Trends and opportunities

Disruptive digital technologies

The quantity and quality of new technologies available for use in agriculture have not only continuously increased over the last few decades but also intensified. Examples of disruptive technologies that are increasingly being used in agriculture for various purposes include nanosatellites (Houborg; Mccabe, 2016), remote and proximal sensors (Mahlein, 2016; Adão et al., 2017), artificial intelligence algorithms (Liakos et al., 2018), drones (Barbedo; Koenigkan, 2018), Big Data techniques (Wolfert et al., 2018), internet of things (Tzounist et al., 2017), cloud computing (Roopaei et al., 2017), blockchain and cryptography (Lin et al., 2017), genomic editing (Chen et al., 2019), 3D printing, robotics (Bechar; Vigneault, 2016), augmented reality (Huuskonen; Oksanen, 2018), and other technologies. Most of these technologies have been discussed in detail throughout this book and are part of the research portfolio being carried out in the context of Embrapa.

Although the offer of such technologies is evidently positive, their usefulness can only be maximized through mechanisms and systems that aggregate the vast amount of data generated by these technologies. More importantly, such tools must be able to generate information that can be immediately used in decision-making. These aggregating technologies will play an increasingly fundamental role in all productive sectors, which is demonstrated by the investments that have been made towards this end (Rose et al., 2016).

Increasing the impact of this type of integrated systems faces major challenges. In particular, the appropriate integration of data from different sources will still require substantial research efforts. Significant advances have been achieved in some areas: feedback between genotyping and phenotyping has been successfully applied in many genetic improvement efforts, and meteorological data have been integrated with information obtained through images to determine the phytosanitary status of crops (Mahlein, 2016). However, it is likely that there is a high degree of complementarity between different types of data that have not yet been explored, causing many technologies not reaching their full potential. Another important challenge regards creating mechanisms for integrating systems to deal with the heterogeneity of potential users. In addition to the level of education that varies considerably, it is important to take into account the different type and level of information each user expects to receive. While most users want to receive fully processed data in the form of information directly related to decision making, there are those who want a more detailed report of what happens on the property. Thus, greater flexibility in data visualization through a user-friendly interface is also an important objective in the near future.

It is important to note that emerging technologies may cause major changes that cannot yet be predicted, such as quantum computing, which can speed up calculation in systems that involve massive calculations, such as simulating scenarios about climate impacts in different areas, price volatility and market fluctuations (Preskill, 2018; Woerner; Egger, 2019), and swarm robotics, in which a large number of robots act in a coordinated manner to collect data (Bayindir, 2016). These are technologies that can significantly change the current scenario, giving way to new possibilities that are not yet viable at the current stage.

Training in digital agriculture

Numerous public and private initiatives seek to increase training in digital agriculture for rural producers, which also favor the process of young people remaining in the countryside. An innovative example is

SENAR (2019), which offers courses in precision agriculture, providing information on the state of the art in agricultural techniques for rural management, promoting rationality and efficiency in production. Another initiative comes from SEBRAE (2019), which provides support to small producers through technological service providers, such as in digital agriculture.

In addition to the availability of online platforms, applications and courses from various research centers, the actions of the Precision Agriculture Research Network (Embrapa, 2018b) are highlighted. These actions generate scientific knowledge, provide technical publications and train multipliers/extensionists on the variability of production and of soil and environmental parameters, of plants, pests and crops diseases such as soybean, corn, cotton, wheat, eucalyptus, sugarcane, orange, grape, apple and peach. At the Brazilian higher education level, BNDES (National Bank for Economic and Social Development, 2017) points out the need to incorporate new disciplines related to IoT and precision agriculture in the courses offered in rural areas, as well as expand the offer of extension courses and postgraduate courses to train technology specialists with agricultural knowledge.

Thus, there are opportunities to provide greater dynamism and integration between research, teaching, industry, commerce, technical assistance and rural extension; take advantage of the more connected rural world and improve the distance education process in the countryside. Digital training can attract more young people to generate more interdisciplinary solutions in the day-to-day life of rural properties, increasing productivity with less pressure on natural resources. An innovative, entrepreneurial and multiplier profile is essential for all who seek digital transformation in agriculture.

Consumer market in the digital age

The higher level of consumer information, made possible by social networks, allows raising awareness about the quality and origin of food and the socio-environmental responsibility of agricultural production systems. The various information and communication technologies benefit the rural-urban relationship by better understanding the role of each sector, enabling to value regional culture and local products, help valuing and maintaining biodiversity, and support rural tourism. Conventional businesses will be developed from the perspective of the digital market, in which the relationship between consumers and customers will be strengthened through business ecosystems, the intensive use of automation and the convergence of ICT in agriculture (Embrapa, 2018b).

The digital economy with cryptocurrencies also boosts virtual cooperatives, new businesses, and digital platforms with direct producer to consumer integration. Bolfe and Massruhá (2020) emphasize that in this technological revolution, people are the main protagonists who will increasingly have a decisive role in decision-making, because, through digital technologies, people will be more demanding and will require more information about the products consumed.

According to a study conducted by CEPEA (Luiz de Queiroz Superior School of Agriculture, 2020), the current covid-19 pandemic can potentially change society’s habits even more, by increasing awareness and efforts to meet hygiene and health levels known to science, but not yet prioritized. It is highlighted that different countries must adopt more robust health protocols, and in addition, they need to raise the global discussion on the consistency of disease surveillance and control systems, which affect animals and humans, to ensure food supply and safety.

In this scenario, only the producer that incorporates new digital technologies will be able to provide more transparency in their production process and will respond to the demands of the national and international market. Thus, there are great opportunities for the development of technologies aligned with digital transformation, which generate information about origin, quality, production methods, environmental and social impacts of agricultural production, among others, such as animal well-being and adequate use of agricultural inputs.

Digital platforms

The growing digital transformation of agriculture drives the demand for solutions that integrate property, production and marketing management information, which are available to rural producers via computers or smartphones. In this context, research institutions, universities, large companies, startups, cooperatives and associations have invested in the development of digital platforms, providing innovative solutions with the integration and analysis of data via geostatistics, artificial intelligence, cloud processing and computer vision.

SigmaABC is an example of a platform that integrates user information (farms, fields, machines and implements, production costs) with data collected in the field, geophysical surveys, phytotechnical data, automatic meteorological stations, global models and regional weather forecasting, mathematical models (diseases, pests, weeds, soil water, potential yield) and remote sensing models (vegetation indices) at different spatial and temporal scales (Fundação ABC, 2020).

Another digital platform format in agriculture is AgroAPI, which offers agricultural information and generated models (Embrapa, 2019). (Embrapa, 2019). It provides opportunities to generate new products and businesses for companies, startups, public and private institutions to create software, web systems and mobile applications for the agricultural sector, with reduced costs and time. Access to information and models is performed virtually, through Application Programming Interface (APIs). These applications include a set of standards and programming languages that allow, in an automated way, agile and secure communication between different systems.

The platforms for the sale of beverages and foods are also consolidated realities in Brazil, and they serve countless consumer profiles. With the current pandemic associated with covid-19, e-commerce giants are leveraging their capabilities in logistics, supplies and technology to also supply urban centers, especially in Asia. RaboResearch (2020) highlights that these companies can further solidify their power of influence with consumers, linking rural producers and processors to distributors and retailers, effectively organizing agricultural production, processing, management of inventories and distribution channels.

Opportunities are also highlighted for the coming years concerning the development of integrated digital platforms, on topics such as: a) support for data analysis and decision-making on the property, with geospatial information on agriculture, vegetation, soil and water resources to support Environmental Regularization Programs (PRA), Environmental Reserve Quotas (CRA) and Payments for Environmental Services (PSA); b) connectivity between rural producers and consumers, supporting the traceability process and certification of the quality and origin of products such as milk, honey, eggs, meat, grains, fruits, sugar, biofuels, fibers, wood and cellulose; and c) support for decision-making and the management of agricultural public policies, based on mathematical, statistical and computational models, with the use of artificial intelligence, computer vision and remote sensing image processing (Embrapa, 2018a, 2018b, 2019).

Future risk projection systems

Climate change has always been one of the main factors in determining the risks to agricultural activities. Using the tools available today, it is necessary to compile, systematize and update information on the possible impacts related to the rising temperatures in Brazilian agriculture related to climate change. For the purpose of short-term planning, all the information currently made available by Embrapa for supporting property management and agricultural production, such as WebAgritec, ZARC Plantio Certo, SatVeg and Agritempo, are sufficient for decision-making.

However, for medium and long-term projections and analysis of future risks in agriculture, one of the challenges is incorporating regional climate models, which allow evaluating the future behavior of crops in terms of climate risk and productivity. Embrapa, on an experimental basis, is developing a new system called the Agricultural Scenario Simulator (ScenAgri) (Embrapa, 2020), which incorporates the aforementioned aspects and combines the foundation of Agricultural Zoning of Climate Risk (ZARC). The system is based on high-performance computing to support researchers investigating the impacts of climate change on Brazilian agriculture. Some studies have already shown the importance of this future projection in the medium and long term for diseases of plants, forages, eucalyptus, grains and sugarcane (Ghini et al., 2011a, 2011b; Marin; Nassif, 2013; Assad et al., 2016).

In the near future, rural producers may have, in their applications, systems that show the crop vulnerability to climate in the short (Plantio Certo), medium and long-term (SCenAgri) conditions. As pointed out above, one of the main challenges is to solve the problem of treating a large amount of data in the models, but technological advances will allow reducing this limitation as an impediment in the medium term. The main sectors that have looked for information about future climate impacts are pulp and paper, citrus and beef cattle.

With the increase in greenhouse gas emissions, resulting from anthropic actions, and its negative consequences for natural ecosystems and for the certification of Brazilian agricultural products, another great opportunity is related to technological solutions that incorporate the determination of the balance of greenhouse gas emissions by production systems. These technologies are based on the Greenhouse Gas Protocol (GHG) and are as the basis for Low Carbon Beef (LCB) or Carbon Neutral Beef (CNB) certifications (Alves et al., 2018).

Thus, in the future, in addition to the recommendations contained in the WebAgritec system, costs per production system and the calculation of the balance of emissions based on the GHG protocol will be incorporated. Thus, at each crop cycle or integrated systems, the rural producer will have the productivity and the carbon “footprint” on his rural property, which will help in the certification of his product. This certification takes place with the analysis of the balance of emissions, which will be carried out after the assimilation of emission factors originating from the Ministry of Science, Technology and Innovation´s National Inventory of Greenhouse Gases.

Traceability and certifications

Based on new national and international consumption patterns, food certification traceability processes have intensified in recent years. A study by Embrapa (2018) on the future of Brazilian agriculture for 2030 highlights that the traceability of products that contain information on their place of origin, inputs used, harvesting, slaughtering, processing, conservation, quality, storage and transport will become an essential condition for customer service, which will require transparency in relation to such characteristics.

Porpino and Bolfe (2020) emphasize that the search for certification of food products by Brazilian companies is an increasing pressure imposed by the consumer market, which demands guarantees about the nutritional, sanitary and hygienic characteristics of foods. There is a set of regulations and standards created by the National Health Surveillance Agency (ANVISA) and by the Ministry of Agriculture, Livestock and Supply for certain certifications, such as the "Good Manufacturing Practices" (GMP) and the Federal Inspection Service (SIF). In addition to the described general certifications for food safety, there are increasing opportunities for agriculture to reach more demanding markets and consumers for processes and products with specific certifications, in particular: Socioenvironmental certifications such as Fair Trade, Certified Humane, Rainforest or Organic (Brasil, 2003); Good Agricultural Practices (FAO, 2016); Animal Welfare (Brazil, 2017); Geographical Indications (National Institute of Industrial Property, 2019); International Organization for Standardization (2020); and Food Safety System Certification (2020). These certifications consider the complexity of agriculture and are based on nationally and/or internationally recognized metrics, criteria and protocols.

New opportunities are also envisioned for digital agriculture facing innovation challenges (Embrapa, 2019), which highlight the need to:

a) Provide digital and cyberphysical solutions to support the identification, traceability, sensing and certification of livestock and animal and vegetable products. A great deal of support for traceability can come from the use of blockchain technology, as it provides a large distributed database that can track what happened in the various links of the production chain.

b) Expand granting the certificates of geographical indication to agricultural products and processes, with intrinsic value and proper identity of the place of origin, such as soil, vegetation and climate.

c) Optimize traceability and certification in accordance with standards of control agencies and consumer demands in the animal protein, eggs, milk, fruits, vegetables and grains chains.

d) Expand the traceability and rapid diagnosis of pathogens, toxins and drug residues carried by food of animal origin, of economic and public health interest.

Society 5.0

Digital agriculture, also known here as "Agriculture 4.0", has been presented as an alternative to solve major agricultural challenges. Note that digital agriculture extends the idea of observing, measuring and connecting intelligent machines from precision agriculture to Big Data platforms and automated machine learning, sensors, satellites, drones and robots.

Digital technologies are facilitators that can optimize agricultural planning and production processes to achieve sustainability goals, enable better decision-making and remodel the functioning of agrifood markets, improve the quality of life of agricultural workers and the rural population, being able to attract a younger generation to agriculture and new rural businesses.

The robustness of Brazilian agribusiness favors the use of these new technologies, but the country is still having to overcome challenges related to training, telecommunications infrastructure, regulation, standard-setting and information security, in addition to high costs. Without a doubt, the covid-19 pandemic marked the end of the 20th century and, officially, the beginning of the 21st century, operating as an accelerator of futures, starting a new revolution in modern society.

After significant progress in mechanization, electrification, information and network technology, modern society has entered a new technology development era: the parallel era of dual virtual and augmented reality technology. Similarly, our society is shifting from a machine society (Society 1.0), electrical society (Society 2.0), information society (Society 3.0) and network society (Society 4.0) to its fifth paradigm: the parallel society or 5.0 Societies (World Economic Forum, 2019), in which there should be no separation between the physical and virtual world.

The basic research theory in Societies 5.0 is parallel intelligence, which is a new methodology that extends traditional theories of artificial intelligence to those emerging from cyber-physical-social systems (Cyber-Physical-Social Systems – CPSS) (Zhang, 2016). This concept of parallel intelligence can be presented as one of the enabling technologies for a more predictive and intelligent agriculture, which can contribute to meeting the new demands for increased sustainable production and productivity in three dimensions: economic, environmental and social. It is in this context that the concept of Agriculture 5.0 is inserted, which, in addition to the massive use of artificial intelligence and biotechnology in agricultural productive processes, it will ensure the production and distribution of food in a more economical and ecologically efficient manner than is currently practiced (Fraser; Campbell, 2019).

In addition to greater demand for food, there is another trend towards behavioral change in populations, which is due to growing urbanization, increased life expectancy, new work relationships and access to information. This combination brings to the environment of cities the concept of "urban agriculture" (FAO, 2011), which includes different aspects, such as indoor production, in controlled environments, combined organic production, raising bees and small animals, community gardens, production on roofs, etc.

In the context of urban development, the preservation and conservation of the environment must be taken into account, and other examples: promote collection, treatment and recycling of solid waste, using water rationally, using clean energy efficiently, develop and use digital technologies and innovative business models such as the internet of things (IoT) and wearable technologies, use autonomous vehicles, circular and shared economy, ensure zero net emission of greenhouse gases and propose new housing solutions, taking into account the principles of sustainable development.

Final considerations

Brazil has an innovative role in the global context of the digital transformation of agriculture. Mobile applications support decision making on numerous practices involving animal and plant production. The use of applications has increasingly supported the monitoring of phytosanitary conditions, the application of pesticides, biological control, animal welfare, soil management and irrigation management. Planning activities associated with the ZARC and the Rural Environmental Registry (CAR) are already part of the day-to-day activities of rural properties. These instruments support land use and occupation planning, the recovery of degraded areas, the implementation of more resilient and low-carbon agricultural systems, such as integrated crop-livestock-forestry (ICLF) and no-tillage.

However, there are still important scientific, technological, social and economic challenges to be overcome in order to integrate the digital transformation of Brazilian agriculture in the different agricultural classes and regions. There are also countless opportunities for research institutes, universities, companies, startups, cooperatives, associations and unions to generate more integrated digital solutions for planning, managing, harvesting and marketing products such as milk, honey, eggs, meat, grains, fruits, sugar, biofuels, fibers, wood and cellulose (Figure 2).

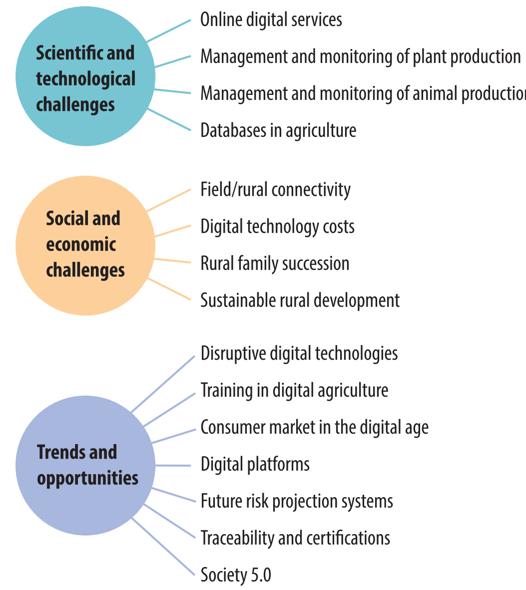

Figure 2. Main challenges and opportunities in the digital transformation of Brazilian agriculture.

The pandemic linked to covid-19 is accelerating and shaping the digitalization of all links in agricultural production chains. The need for greater food security, with the possibility of using technologies that reduce physical contact, drives new applications from input suppliers to rural producers, from marketing to transport, and from distribution to final consumers.

In the "new normal" post-pandemic, digital connectivity and content services associated with links in the chains could expand with the growing concerns about the health of populations and the sanitary and nutritional safety of food. Public and private managers, entrepreneurs, service providers and rural producers need to consider, in their decisions, the aspects of digital transformation and its implications and interconnections with other links in the production chains and food security. E-commerce giants have taken advantage of the already installed capacity in logistics and distribution to sell food products in certain urban centers worldwide. However, digital gaps between the poorest and richest families, as well as between rural and urban populations, will probably persist.

These and other conditions are foreseeing the future of digitization of Brazilian agriculture, when research, innovation and business are expected to expand rapidly in infrastructure and services such as:

- Cognitive artificial intelligence for monitoring production.
- Multi-scale and multi-source analyses of agricultural risks.
- Real-time monitoring of properties by remote sensing.
- Machine and equipment maintenance of prediction systems.
- Processing of agricultural big data and small data in the cloud.
- Sales platforms via short circuits integrating producers and consumers.
- Distance learning and work applications with safe administrative procedures and social interaction of staff teams.
- Blockchain and digital encryption technologies for the security of commercial transactions and the traceability of products and food.
- Technical-financial management systems considering economic, environmental and social aspects of the property.
- Security and privacy of data and information generated in all digital processes.

Hence, the digital transformation of Brazilian agriculture will play a far more relevant role in the coming years regarding the production of food, fiber and energy in greater quantity, quality and sustainability.

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