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Driving forces for Brazilian agriculture in the next decade

Implications for digital agriculture[1]

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Introduction

Brazilian agriculture is not isolated in an economic vacuum. Agriculture influences and is influenced by its surroundings. Given Brazil's status as an important player in global agricultural markets, these dual avenues of influence expand to include regional and global dimensions.

In the last decade, different aspects of digital agriculture and its sectoral applicability were presented to the productive sector. These advances include sensors, images from mobile devices, drones and satellites, internet of things (IoT), Big Data, computer vision, simulators, optimization algorithms, and artificial intelligence. The integration of these technologies has the potential to transform agriculture and livestock production. This change would be translated into improvements in management and decision-making processes, as well as efficiency gains at different stages of production.

The expansion of digital agriculture's relevance in production processes in the next decade seems, therefore, inevitable. This reflects the potential benefits these digital technologies and services can add to the agricultural production chain, at gradually lower costs, and with increasing efficiency. However, despite

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the growing availability of solutions in information technology (IT) presented to the market, actors in the private sector sometimes point to the lack of objectivity and applicability of the information presented. They frequently point to the lack of economic analysis supporting the proposed digital solution.

These findings suggest that general approaches to digital agriculture have been prioritized. Although interesting for the dissemination of technologies, that approach does not provide objective elements for the producer's decision-making. Digital solutions need to be analyzed based on the grand challenges and opportunities that Brazilian agriculture faces in order to be effective in the real world. These important issues, roughly speaking, can be grouped into micro, macro, biological, and management dimensions. The environmental dimension is transversal to these other dimensions.

This chapter proposes to briefly reflect on these topics, emphasizing the key driving forces on the demand and supply sides that shape and strongly interact with major challenges and opportunities observed in Brazilian agriculture. In addition to this introduction, the second section will discuss the main relevant driving forces to agriculture, outlining situations of interest for the potential insertion of digital technologies in agricultural systems. The third section presents digital agriculture in the context of the production chain. The fourth, and final, section explores some perspectives that are beginning to take shape in the domestic and international environments and that may bring about pressures, but also opportunities, for Brazilian agriculture (and for digital solutions) in the near future.

Relevant driving forces to agriculture and its digital transformation

Thinking about the future, whether in the short term (operational level) or in the long term (strategic level), is an intrinsic human trait (Harari, 2015). Recent studies have synthesized future opportunities and challenges as regard the sectoral, regional and temporal scope (Embrapa, 2014, 2018; Boumphrey; Brehmer, 2017; FAO, 2017; The Economist Intelligence Unit, 2019; Global, 2019; Kirova et al., 2020). Terms such as driving forces (or drivers), trends and megatrends are intertwined, sometimes get confused, and have been used to describe potential forces and impacts, either positive or negative, to the public and private sectors.

An interesting contribution to understanding these terms (and their application) was presented by Boumphrey and Brehmer (2017). According to these authors, the driving forces shape the megatrends, which are, thus, a second-order phenomena. Megatrends are well-established forces of medium- to long-term influence (5 to 15 years) in a world explained by the driving forces, whose evolution permeates different sectors of the economy and takes different forms over time. For a force to be considered a megatrend it must have multi-sector relevance. If this force is sector-specific, despite any potential to influence the sector, it is not considered a megatrend in the strict sense of the concept, instead, it is considered a trend.

In many situations, the description of how these megatrends and trends are relevant to planning within its different time horizons is often too vague, which does not contribute to decision-making process. Alternatively, reflections on future opportunities and challenges, based on driving forces, are generally simpler and more objective, in addition to the advantage of having available a robust set of quantitative tools. Thus, when appropriate, credible and verifiable analyses to support planning and decision-making at their different levels can be carried out.

The driving forces refer to changes induced by factors of natural or human origin that occur in (agro) ecosystems. These changes can have a direct or indirect effect (Nelson, 2005). The driving forces of direct action are climate change, land use changes (such as deforestation), plant's nutrient use efficiency, and the incidence of pests and diseases. Those with indirect action operate more diffusely, altering at least one direct driving force, which will eventually influence the (agro)ecosystem processes. The most important indirect driving forces are those of a demographic, economic, socio-political, scientific-technological, cultural, and religious nature (Nelson, 2005).

Driving forces act at global, national and local levels and present interactions between these different scales (Hazell; Wood, 2008; Embrapa, 2014). Awareness of these driving forces, their importance, potential impacts, and interactions was strongly stimulated from the 1990s onwards, with communication possibilities opened by the internet along with the declining costs in IT equipment and services.

On a global scale, factors such as climate change, globalization, foreign trade, international prices of food and inputs for agricultural production (including energy), policies (agricultural, environmental, etc.), among others, interact with factors at the national level. At the country level, there are other influencing factors, such as those of macroeconomic and political nature, legal issues, market channels, per capita income, and urbanization. The national scale mainly, but also the global scale, further interacts with the local level, in which factors such as infrastructure, access to markets, agroecological zoning (and environmental restrictions), employment, incentives (public policies) and disincentives (taxes) are shown to be active (Hazell; Wood, 2008).

Determining the relative importance of each force, direct or indirect, as well as their interactions on the impacts observed at a given location is not a trivial task. Nevertheless, strategies to respond to eventual undesirable changes will be motivated by the ability of local agents to influence these drivers. Thus, notwithstanding the difficulties, it is important to focus on the factors that most influence opportunities and challenges at the local level (Hazell; Wood, 2008).

At the local level, a farmer's perceptions about the relative importance of these forces in terms of pressures on available resources, restrictions and opportunities to business, subject to his/her individual values, guide the course of decision-making. The farmer's perspectives regarding opportunity costs and risks involved in decision making are unique to a given farmer-farm combination. This happens because the quantity and quality of resources (land, labor, physical and human capital) and inputs, as well as the relative prices involved, vary on a case-by-case basis.

Therefore, analyzing these driving forces provides elements that support reflections and actions in the public and private sector, thus guiding the definition of plans, goals, and objectives. For research and technology transfer, they indicate the direction of priorities and strategies for programs and projects. The growing possibilities offered by information and communication technologies (ICT) allow greater interaction between relevant actors and agents with interest in agriculture. This interaction has increasingly included other important stakeholders, from Brazil and abroad, in discussions related to agriculture and its production environment.

An interesting way to analyze the driving forces and their impacts is through the economy's supply and demand model. This analysis framework incorporates many of the signs provided by the different driving forces. Thus, the main factors related to the increase in demand for agricultural products are variations in population growth and per capita income. Factors such as the urbanization rate and the preferences of individuals, subject to cultural, socio-political, and religion, also influence the shift in demand.

Demand-side factors, which reflect society's main preferences, influence decisions regarding the agricultural production process (supply). The main driving forces related to variations in agricultural supply are the availability of technologies and the costs of production. Digital solutions (technological supply) can contribute favorably to efficiency gains in management and in the production process. This makes room for reducing production costs, in addition to creating opportunities for the expansion of income for farmers and, more broadly, for the actors involved in the production chain.

Key-driving forces on the demand side

The two main shifters of the demand curve are population growth and per-capita income. Hertel and Baldos (2016) estimated that between 1961 and 2006 a population growth rate of 1.7% per year in the period explained 83.7% of the variation in agricultural demand. The variation in income in the period, 1.4% per year, accounted for the remaining 16.3%.

The most recent projections from the United Nations indicated that the world population in 2050 will be in the range of 9.4 billion to 10.1 billion, representing an average expansion of 0.8% per year compared to the population of 2019, of 7.7 billion (United Nations, 2019). Per capita income will grow in importance as a driver explaining the expansion of demand in the decades ahead (Guillemette; Turner, 2018).

Hertel and Baldos (2016) were able to capture these developments using as reference the period from 2006 to 2051. In this interval, the simulated population and per capita income growth rates were 0.8% per year and 2.1% per year, respectively. Under these conditions, the projected increase in agricultural demand for the 2006–2051 period due to variations in population growth and per capita income are, respectively, 35.4% and 149% higher compared to the 1961–2006 period. The decomposition of these forces for the 2006 – 2051 horizon revealed that population would explain 55% of the growth in agricultural demand, while per capita income would explain the remaining 45%. In the period extending to 2050, most of the global population variation will be concentrated in Africa (59.2%) and Asia (33.5%) (United Nations, 2019). Income, as an explanatory factor for the increase in agriculture demand, has Asia as the main region, followed by Africa (64.6% and 21.1% of the total variation, respectively) (Hertel; Baldos, 2016).

These forces, combined with changes in eating habits resulting from the expansion of the world middle class (Kharas, 2017) and the growing rate of urbanization (Warr, 2019), will sustain the demand for agricultural products in the next decade. The demand growth rates for products with higher income elasticity, such as animal protein, should be higher in emerging countries (Godfray et al., 2018), whose population seeks to reach consumption levels close to those observed in rich countries. The aging of the population (United Nations, 2019) and possible changes in diet preferences motivated by claims for healthier food and environmental issues (Godfray et al., 2018) should reduce the rate of increase in the demand for animal protein in the future. However, eventual structural and large-scale transformations are complex processes that take decades to be carried out (Elzen et al., 2012).

Agricultural demand and covid-19

The pandemic has caused a unique situation in human history, both in characteristics and proportions, as its deleterious consequences have simultaneously affected health and economy in different regions of the world.

Expectations of economic growth in Brazil and in the world have rapidly deteriorated over the first semester of 2020. The world's Gross Domestic Product (GDP) for 2020 showed a negative variation of -3.1% (International Monetary Fund, 2021), representing a 6.1 p.p decrease compared to the pre-crisis scenario (variation from +3% to -3.1%) (European Commission, 2020a, 2020b, International Monetary Fund, 2021). The Brazilian economy shrank 4.1% in 2020 (International Monetary Fund, 2021), which represents a drop of 6.4 p.p compared to pre-covid-19 growth projections.

The economic recovery has been slow and quite uneven between countries, between regions of a given country, and between different sectors of the economy. In 2021, the world economy grew 5.9% and the world GDP is projected to expand 4.4% in 2022 (International Monetary Fund, 2022). However, the Brazilian economy has not performed at the same pace. It grew 4.7% in 2021, and it is projected to stay close to stagnation in 2022 (e.g. GDP variation of only 0.3%) (International Monetary Fund, 2022).

There is still a great deal of expectation about the effectiveness of the economic emergency measures implemented by governments and their future impacts. In the Brazilian case, the latest Focus Report available[2] from February 21, 2022, projected an official inflation rate (e.g. IPCA) of 5.56% for 2022. That inflationary pressure is forcing Brazil's Central Bank to raise the basic interest rate (e.g. SELIC) in the economy, that is already projected to reach 12.25% in 2022 according to the latest Focus Report. The situation could worsen given the uncertainties regarding the possibility of new Covid-19 variants cycles over the next few months.

Agriculture has shown to be resilient and one of the few sectors capable of sustaining a positive variation in sectoral GDP, having registered a 2% growth rate in 2020 (IBGE, 2021). However, the impacts of the pandemic on the food sector demand in the short term and immediately after the pandemic, are likely to be asymmetric among its subsectors. This asymmetry reflects, among others, restrictions due to social distance, the deterioration of per capita income in the coming months, the availability of substitute products and the income-elasticity of demand for products.

The "food at home" group has been the least impacted by the Covid-19 crisis. Even so, according to income stratum, a slowdown in demand may reach -3.7% over the next year, compared to pre-crisis expectations[3]. Food groups with greater income-elasticity, such as meals away from home, organic, and animal protein segments are expected to be more heavily impacted. Depending on the case, the drop in demand over the next year may exceed 9.0% compared to the pre-crisis scenario (Martha Júnior, 2020).

Globalization and international trade remain essential for economic development. However, it is expected that there will be growing support to nationalize the production of a greater variety of inputs in order to support the production process within national borders. At the same time, there is a trend towards more demanding consumers asking for more qualified information on agricultural products, services, and environmental and social variables related to production (and eventual externalities).

Within this scenario, it is plausible that the growth of exports may face a more intense and competitive environment, particularly in view of the sharp per capita income drop caused by the covid-19 pandemic. Despite these uncertainties, for the time being, there are positive expectations for the expansion of Brazil's participation in global agricultural markets over the next decade. However, meeting the increasingly diverse and rigorous demands and capturing opportunities is neither negligible nor free of challenges.

Some digital technologies are expected to significantly grow in this context. The previously discussed trends point to a rapid expansion in the demand for digital solutions in monitoring, traceability of

[2] The Focus Report, by the Central Bank of Brazil (BCB), "[...] summarizes the statistics calculated considering market expectations collected up to the Friday prior to its release. It is released every Monday. The report presents the graphic evolution and weekly behavior of projections for price indices, economic activity, exchange rates, Selic rate, among other indicators. Projections are from the market, not from the Brazilian Central Bank[...]" (Banco Central do Brasil, 2020). It is worth of mentioning that Selic, an acronym originating from "Sistema Especial de Liquidação e de Custódia", is the basic interest rate in the Brazilian economy. It is the main monetary policy instrument used by Brazil's Central Bank to control inflation, and it thus influences interest rates on loans, financing and financial investments, etc.

[3] Constant prices are assumed, therefore not incorporating the dynamics when prices adjust. A drop of 6.50% in GDP per capita was considered, with reference to information in the Focus Report of June 19, 2020.

products, and the behavior of system's variables (sensors, geotechnologies, Big Data, etc.). The objective in expanding these digital solutions is to increase the amount of information about origin, safety, food quality, and agricultural production models, as well as their potential impacts in the environmental and social dimensions.

Key driving forces on the supply side

The supply side reflects the quantity of goods and services that producers choose to place on the market in a given period. Nevertheless, agricultural production is not a quick process. Decisions on what to produce, and with which technological packages take months in advance before harvesting grains, such as corn, or oilseeds, such as soybeans. In livestock and fruit production, and in the forestry sector, the delay between production decision-making and final results takes years. Thus, expectations regarding prices (products, inputs), production volume and associated risk variables (e.g., price and productivity) are extremely relevant in the decision-making process.

In the very short term, the producer has limited capacity to change production level and the technological package. In the short term, fluctuations in weather conditions and price volatility resulting from uncertainties on supply and demand, and speculative movements in the market, increase the risks in agricultural production and its market. Periods of great uncertainty, such the new coronavirus pandemic, introduce a greater degree of risk to the agricultural business, determine additional challenges to agricultural policies (producer's income and supply to consumers), and influence decision-making at different levels.

Decisions regarding production and the adopted technological package are adjusted by the farmer as time increases. The longer the time, the greater the possibility of implementing adjustments. In the longest term, all factors may vary. In the long run, generating and incorporating technological innovations into agricultural production systems have been the main and most successful strategy to ensure greater food supply and food security for the Brazilian population, which is mostly urban nowadays, ensuring viable economic conditions for farmers (Martha Júnior; Alves, 2018).

The technological packages developed for Brazilian agriculture, among others, include improved genetics, fertilizers, agrochemicals, cultural practices and conservationist production systems, such as no-tillage and crop-livestock-forest integration. More recently, technological possibilities have expanded and incorporated digital solutions into the universe of viable technologies. With the adoption of these different forms of technology, the goal is to effectively increase productivity gains in the use of resources and inputs. These are strategic aspects for the sustainability and competitiveness of national agriculture.

The role of technology in Brazilian agriculture

The overall style of development in Brazilian agriculture has been predominantly based on productivity gains, reflecting the increasing incorporation of technologies into the production system. Alves et al. (2013) worked with data from the 1995/96 and 2006 Agricultural Censuses and investigated the determinants of income in Brazilian agriculture. Within a decade, technology, drawing on the entrepreneurship of producers, public policies (such as rural credit), and the available stock of knowledge and technologies in tropical agriculture began to explain 68% of the variation in gross income in agriculture. This represented a 33% increase compared to 1995/1996. In the comparison between the Agricultural Censuses, the contribution of land and labor to the variation of income in agriculture was reduced by about 50% (from about 18% to 9%) and 30% (i.e., from approximately 31% to 22 %), respectively.

Therefore, land and labor, as factors of production, lost their relevance in explaining the development of a science-based agriculture, like the Brazilian one. Technology is the major driver behind the sustained development of Brazilian agriculture in recent decades, as well as for future projections. The positive response to investment in agricultural research, with returns higher than 10% (Hurley et al., 2014), occurs over long periods, usually over 20 years, depending on the technology (Alston, 2010; Baldos et al., 2018). Given this long period of maturation of agricultural research, the listed results were only possible due to a persistent and focused work in agricultural research and development (R&D), with a focus on innovation, which has been actively developed in Brazil since the 1970s.

It is anticipated that digital solutions will gain relevance in the coming decades, reinforcing the role of technology as a major driver explaining income in Brazilian agriculture. This happens because of the wide set of databases, technologies, and resources that make up digital agriculture, crosscutting to traditional technological aspects. These advances begin to gradually play a more important role in the management and efficiency of the technological component of national agriculture.

A brief reflection on risks in agriculture

Farmers carry out their activities in a dynamic and uncertain environment. Expectations (and volatility) for the prices of products and inputs guide their decision-making. According to the perception of business risk, farmers can opt for lower risk activities, even if this implies compromising the average income of the farm (Barry et al., 2000; Chavas, 2008; Moss, 2010). The level of risk aversion of individuals can vary over time according to wealth and previous experience, among other factors (Barry et al., 2000).

Variations in weather conditions can compromise the expected production results depending on the intensity, duration, and moment in which they occur in the production cycle. This weather production risk is a random effect, beyond the farmer's control, except in irrigated areas, which in Brazil make up less than 10% of the total cultivated area. Furthermore, Brazilian agriculture operates in soils with low chemical fertility and, throughout the entire production cycle, is pressured by the possible incidence of pests, diseases, and weeds. This makes it dependent on the continued use of modern inputs to remain productive, which nevertheless can accommodate substantial gains in agronomic and economic efficiency.

With unfavorable relative input-product prices, efficiency in the use of these inputs needs to increase to alleviate pressure on farmer's income. Digital technologies can act directly to increase efficiency gains and reduce production costs. The available precision farming instruments allow for improved adjustment in quantity requirements for a range of inputs, such as fertilizers, seeds, agrochemicals, fuels. Advanced models that support decision-making allow, within certain limits, to reduce the negative impacts of some forms of risk. Thus, intelligent warning systems enable adjustments in management, making it more effective in the face of pressures from diseases and pests or the effects of seasonality in forage production in pastoral systems.

Agricultural commodity prices are more volatile, e.g., they fluctuate more over time in relation to price volatility of other non-food goods and services (Tomek; Robinson, 2003). Among agricultural commodities, prices for beef cattle are generally less volatile (e.g., lower price risk for economic agents) compared to the prices of other products, such as soybeans or corn. Wedekin (2017) illustrated this fact by analyzing the price volatility of several agricultural commodities on the stock exchange, from January 2010 to February 2017. The volatility, expressed in percentage per year, for fed cattle, calf, soybeans, corn, coffee, and sugar was 11.0%, 17.0%, 23.1%, 24.6%, 32.6%, and 34.1%, respectively[4].

[4] Volatility is generally estimated based on daily price variation, however it is expressed as a percentage rate per year (Wedekin, 2017).

Within the scope of price risks, it is also necessary to consider the exchange risk in the sale of these products when purchasing inputs. Another important factor is the behavior of relative input-product prices, which are important in determining the level of production. In general, output and input prices are positively correlated (Tomek; Robinson, 2003), but the adjustments to changes in relative output-factor prices can take some time.

Price expectations in Brazilian agriculture gain complexity as a growing portion of national production is directed to exports and, therefore, the international market is a strong component of the price reference. It should be noted, however, that this growth in exports has not compromised the domestic supply and food security of Brazilians (Martha Júnior, 2020).

There are two pertinent additional considerations. First, digital solutions, as inputs to agricultural production, have their adoption subject to the perception of benefits and relative input-product prices. The second consideration is that the biggest opportunities for the group of digital solutions whose value depends on the information they provide for decision-making lies in their use to reduce production and market risks, the so-called business risk. This is due to the increased capacity to observe and capture (sensors, satellites, drones), record, and store data (Big Data, cloud storage), which once transferred and gradually used at greater speed (IoT), through advanced algorithms and models, allow basic and applied solutions (artificial intelligence, analytics) to be applied for the "real world". This increases the efficiency of management and operations and improves the decision-making process.

The choice-process of technology on rural properties

Two groups of technologies can be identified. The first one, the embodied knowledge type of technologies, is represented by technologies that incorporate large amounts of knowledge, and their use do not require much expertise as the technology value is already incorporated into it. Some examples are hybrid seeds, fertilizers and most agrochemicals. This type of technology is the most successful in twentieth-century agriculture (Miller et al., 2018; Lowenberg-Deboer, 2019). In digital agriculture, an example is Global Navigation Satellite Systems (GNSS) guidance (Lowenberg-Deboer, 2019).

The second group is information-intensive technologies. These technologies generate substantial amounts of data and information, which can then be used in the decision-making process. However, to explore the potential offered by these technologies, it is necessary to analyze and interpret data and information, which requires training and some degree of specialization (Miller et al., 2018; Lowenberg-Deboer, 2019). In digital agriculture, an example is variable rate technology of input application, such as fertilizers (Lowenberg-Deboer, 2019).

Regardless of the type, there are steps that should be used in the process of choosing technologies on a farm. Based on Alves' suggestion (2001), and adapting it to the context of digital technologies, the following are the critical steps for evaluating these digital solutions:

a) Description of the digital technology and of the proposal for its insertion in the production system.

b) Analysis of the strengths and weaknesses of digital technology vis-à-vis the technology that will be replaced on the farm. What are the expected gains?

c) Identification of necessary changes in the current production system and farm management to enable the adoption of digital technology. For example, what is the demand for resources and specialized technical assistance for the proper functioning of the digital solution?

d) Identification of restrictions, in farm's context, that may limit the best performance of the digital solution. For example, what are the limitations of IT infrastructure in the region?

e) Analysis of financial demand and financing possibilities in the case of capital acquisition costs. How does the type of contracting the digital solution affect the farmer's decision-making (fixed versus variable cost)? It is also important to consider whether there is a necessary minimum scale, or minimum prices, to make digital technology viable.

f) Evaluation of risks related to digital technology and the training needs of the farmer/manager.

g) Analysis of impacts (positive or negative) perceived by digital technology on the environment.

In cases where the expected social benefits outweigh the private benefits due to the use of technology, opportunities are created to eventually design a public policy to equalize the two (Alves, 2001). When in society's interest, the adoption of these digital technologies can be induced through a set of appropriate incentives.

An illustrative example

The farmer's perspectives on opportunity costs and risks involved in decision making are unique in relation to a given farmer-farm combination. This is because the quantity and quality of resources (land, labor, physical and human capital) and available inputs, which are subject to relevant relative prices, vary from case to case. Brazilian agriculture is extremely exposed to market signals[5]. Therefore, evaluating the economic performance of the activity is a critical step in the decision-making process.

The cornerstone of costing is the opportunity cost. This represents the value of the best alternative sacrificed for another economic alternative to be realized, given the restrictions on production. Expenses (explicit) and remuneration (implicit) of capital (own or third-party) must be computed. Expenses denote cash disbursements, while rents and interest paid from the use of capital represent how much the firm is sacrificing, in monetary terms, in order to carry out one activity against another alternative.

Table 1 presents an exercise related to soybeans in the 2019/2020 crop. Indicator descriptors are included in the table's footnote. The net return (NR) in the baseline scenario was USD 51.38[6]. This means that, in the situation represented in Table 1, it was possible to fully remunerate all production factors, with a positive balance. The main digital technologies have sought to increase efficiency gains in mechanized operations and in the use of inputs, notably fertilizers and agrochemicals. These three expense items – operations with machinery, fertilizers, and agrochemicals – represented 47.2% of the total cost (TC) in the exercise shown in Table 1.

Some of the potential benefits of digital solutions that can be adopted in the production system already have their cost represented in these expenses, as they refer to embodied-type technologies, which do not require additional remuneration. Alternatively, consider the feasibility of expanding such benefits through information-intensive technologies is being studied. These would allow, for example, to better use productivity and soil fertility maps, and identify crop growth deviations in support to

[5] According to statistics from the Organization for Economic Co-operation and Development, the 1995–2018 level of incentives to Brazilian agriculture ("producer support estimate", PSE) was on average only 1.6% of gross farm receipts. Considering the same period, the average levels of incentives received by farmers in the United States, China and the European Union were 13.0%, 8.7% and 26.9%, respectively (Organization for Economic Co-operation and Development, 2019).

[6] Average dollar exchange rate for 2020: USD 1.00 = BRL 5.1575

decision-making. There is no rule for remunerating these services, but it is estimated that depending on the particularities of each farm, this cost can currently vary between USD 0.97 and USD 7.76 per hectare.

A quick look at the information in Table 1 can reveal that a digital solution costing, for example, USD 7.76/ha would easily be paid for the NR of USD 51.38. However, the producer already has this NR without using the technology under evaluation. Therefore, it is important to look at the difference between the expected economic gain from the use of the digital solution under evaluation and the one already earned, translated by the NR in the baseline scenario. The differences would be, therefore, of USD 7.39, USD 14.77, and USD 44.32 for efficiency gains from the adoption of a digital solution of 2.5%, 5.0%, and 15.0%, respectively (Table 1).

Table 1. Illustration of the potential of digital technologies in reducing expenses and increasing net return in soybean production.

Expense reduction from adoption of digital solutions (%)	Net return (baseline)	Productivity shock	Productivity shock+price shock
	Net return (USD/ha)		
0.0	51.38	0.60	-30.72
2.5	58.77	7.99	-23.33
5 .0	66.16	15.37	-15.94
15.0	95.70	44.92	13.60
Net return, SEM[(1)]	35.58 to 67.19	-15.21 to 16.41	-46.52 to -14.91

Note: Considers 18 Conab panels for the 2019/2020 harvest. Net return (NR) is given by NR = gross return (GR) – TC. The reduction in expenses refers to operations with machinery, fertilizers, agrochemicals. SEM refers to the standard error of the mean, it is a measure of dispersion. For the baseline scenario, there was an average productivity of 53.4 bags (60 kg) per hectare. The average price at the time the decision was taken (2019) was USD 12.67/bag. In the baseline scenario, gross return (GR) is USD 677.11; variable costs (VC) of USD 451.91; total operating cost, TOC (VC + depreciation and other fixed costs) of USD 541.16; total costs (TC; TC= TOC added to capital remuneration and rent expenses) of USD 625.73. The productivity shock considered a 7.5% drop in soybean yield and the price shock a 5% drop in soybean price.

[(1)]SEM = Standard error of the mean.

In this context, two qualifications are possibly relevant. First, in the presence of negative productivity and price shocks, which reduce the returns compared to the baseline scenario, the economic performance of the system deteriorates. However, the differential responses expected by efficiency gains in the use and application of inputs in Table 1 were maintained. To put in another way, if the payment for a digital solution is as a "fixed cost", independent of the productivity level, the decision-making does not change[7]. The optimal decision would remain in place, except when the additional "fixed" expense is of such magnitude as to compromise the positive result of the business in the short term.

For example, with a 7.5% drop in productivity ("productivity shock"), the NR was slightly positive, at USD 0.60. The dispersion of NR, given by the standard error of the mean, ranged from - USD 15.21 to USD 16.41 (Table 1). This condition may indicate that those farmers uncertain about the performance of the digital technology could choose not to use it. If the technology delivers what it promises – in the case illustrated in Table 1 a reduction in expenses with mechanized operations, fertilizers, and agrochemicals

[7] If the payment for a digital solution is variable, depending on the level of productivity, the decision, at the margin, will change. In these situations, each different level of production coinciding with a different pay for the technology, would be optimized at a different level.

varying from 2.5% to 15.0% –, its adoption will improve economic performance, whether by expanding the positive result, or by reducing the negative one, as illustrated in the last column (joint shock of productivity and prices).

A second qualification concerns the relationships between revenue and cost, at their different levels. If the unit cost of production is higher than the product price, the business, as it stands, is not sustainable. In the short run, if the expenses represented by the variable costs were covered, the farmer should remain in the activity if he/she had expectations that, in the future, he/she would be able to fully remunerate the factors of production (NR equal to zero, or even positive in the case of "abnormal profits")[8]. Such expectations could reflect improvement in the price of the product, but which is beyond the farmer's control. In the market close to perfect competition where agriculture operates, the farmer is a price taker. It could, alternatively, reflect a critical and well-done analysis of the system by the decision-maker, in which opportunities under his/her control would be identified in order to improve resources- and inputs-use efficiency, and productivity in a sustained manner. The correct diagnosis, together with the ability to manage and implement appropriate actions, would allow to reduce production costs and/or increase returns and, potentially, obtain a more favorable NR.

The possibilities presented by the new generation of digital solutions allow well-established management tools, but still little used by farmers in their daily decisions to become part of their routine decision-making process, many times in an automatically manner. With the expansion of a range of data to aid farm management and field operations, the situation in which the use of a given resource or input could be maximized can be estimated with more accuracy and precision. And, given the expectations of changes in relative prices or production levels, it would be possible to re-estimate new optimal prices that maximize returns to the farmer.

Digital agriculture in the context of the production chain

Digital solutions act transversally in the agricultural production chain. An interesting example of such applications was presented by U.S. Agency for International Developmen (2019). The applicability of digital solutions ranges from the planning process, advancing to the input industry (pre-gate), to the agricultural production, as widely discussed in the chapters of this book, reaching the manufacturing industry and consumers. Transverse to these links, there is the transport sector and the financial sector, which increasingly benefit from digital solutions. The activities in these different links do not take place in an economic vacuum. Thus, a series of forward and backward effects can be observed in the production chain, which ultimately has the potential to multiply sectorial gains.

Data from CEPEA – ESALQ/USP (Luiz de Queiroz Superior School of Agriculture, 2020) showed that the Brazilian agribusiness GDP in 2019 totaled USD 300.53 billion, equivalent to 21.4% of Brazil's GDP. Of this total, the contribution of the input-industry, agricultural (on-farm) production, transformation-industry, and services sectors was USD 15.34 billion, USD 68.06 billion, USD 90.47 billion and USD 127.24 billion, respectively. The key point made by these numbers is that a strong, competitive, and sustainable agriculture is able to supply the national industry with a flow of quality raw materials at declining real prices, potentially increasing its competitiveness in a sustained manner. However, consolidating the

[8] The "zero" economic cost, considering explicit and implicit expenses, is not the same as the "zero" considered in accounting.

competitiveness and sustainability of a strong science-based agriculture requires modern inputs with high technological content. These are provided by urban activities. Therefore, the country's industrial and service sector has a large market to explore, if they are able to deliver quality products to agriculture at competitive prices (Martha Júnior; Alves, 2018).

Sustained efficiency gains provided by digital solutions can contribute favorably to the expansion of agricultural demand. In a recent work, Takasago et al. (2017) estimated the type II multipliers of production, employment, and income for Brazilian agriculture. The values found were 3.42, 1.84 and 5.55, respectively. Thus, for every USD 1 million increase in the sector's final demand, a total of direct, indirect and induced effects of USD 10.81 million is expected. Additionally, for every USD 1 million shock in the final demand of agriculture, there is stimulus for the creation of 309 total jobs, 170 direct, 36 indirect, and 103 induced. These numbers illustrate the significant potential for the application of knowledge and technologies that improve management and decision-making in farms, with a consequent increase in efficiency gains and reduction in production costs in different production stages[9].

Final considerations

Digital technologies have effective potential to improve the competitiveness and sustainability of Brazilian agricultural production chains in a sustainable way. Observing this potential, however, is not a trivial task.

The first concern regards the phenomenon of sectoral concentration and consolidation. This phenomenon, present in the input segments such as seeds, agrochemicals, fertilizers, and agricultural machinery, is advancing rapidly in the dimension of digital agriculture. Such movements point to greater concentration and consolidation in the agricultural production chain, "on-farm" and in the industry and services segments (Miles, 2019; Mooney, 2019; Klerkx; Rose, 2020).

This context introduces a second aspect, related to barriers to the adoption of digital technologies, and to the policy dimension its capacity to promote a more competitive environment for agricultural production in this coming digital era. One of the main barriers to the broader adoption of modern technologies concerns market imperfections. These change relative prices and the return on investment in technologies, and can lead to a widening of productive inequality. Thus, reducing market imperfections is a necessary condition to expand production in a more inclusive way, and increase the effectiveness of policies focused on implementing technologies in agriculture (Martha Júnior; Alves, 2018).

The adoption of a new technology implies that farmers will consider the proposed technology when they have the perception it is superior (competitive) to other technological alternatives already in use at the farm, especially when the sector operates with low levels of incentives, such as in the Brazilian case. The process of choosing the technology on a farm involves the analysis of several factors, and it is conditioned by the farmer's capacity to assimilate and effectively adopt this set of knowledge and technologies in accordance with the recommendations. In some cases, research and rural extension have difficulty in translating and transferring the existing knowledge and respective recommendations into a language that can be easily absorbed by farmers.

[9] Heath (2018) estimated the potential effects of digital agriculture on the Australian economy. His simulations were based on productivity gains attributed to greater efficiency and to a greater value of production and marketing. It was found that the gains would be in the order of A$ 20.3 billion (about R$ 71.90 billion). About two-thirds of the gains were attributed to automation (labor savings), better understanding of genetics, and management to achieve plant and animal productivity gains with more efficient use of inputs, and improved access to markets.

In this regard, a broad and competent work of pertinent technical-economic analyses and subsequent dissemination of the results is necessary to stimulate their faster implementation. Digital solutions can help reducing some of the forms of market imperfection by allowing: a) faster dissemination of knowledge and recommendations (e.g. contributes to reducing the perception of risk); b) better monitoring of key variables (e.g., makes room for more favorable relative prices and efficiency gains in the management of system's components and their interactions); and potentially, c) greater economic attractiveness of the agricultural business (e.g., driven by traceability and transparency related to product and processes).

A third aspect concerns the behavior of digital solutions vis-à-vis other available innovations to be used in the system. The results observed by evaluating one given technology, in isolation, may not be transferable to situations in which other technologies, digital or not, are simultaneously implemented. The results from the interaction of different knowledge and technologies may be different when introduced simultaneously into the production system.

Furthermore, an increasing number of digital solutions are now becoming available for farmers' decision-making, such as different possibilities in robots/automation, artificial intelligence, and sensors. However, very little is still known about how farmers will make their choices, whether they will prioritize one digital technology or a set of them (Klerkx; Rose, 2020). The choices of inputs and technologies used in the production systems depend on their relative prices and, obviously, on the expected returns from their use. In the short term, substantial variations in factors' relative prices may make the adoption of technologies unfeasible, especially the more capital intensive ones.

The fourth aspect, compounded by the crisis of the new coronavirus, indicates digital technologies are being more eagerly adopted in people's daily lives, as well as in some productive and financial activities (teleworking, electronic commerce, etc.). These changes in the way the economy works can accelerate structural changes, impacting the socioeconomic dimension. Despite some sectors gaining momentum with the anticipation of a more intense digital age, the prolonged high unemployment rates in the strata of less qualified people can be observed. This portion of the population, which has already been harmed by the crisis and by the slow recovery of the economy, may see employment and income expectations further deteriorated as they may lack the skills or familiarity with the minimum tools to participate in this digital age.

With a vision on the future, strengthening the sustainability and competitiveness of Brazilian agriculture requires a solid base in agricultural research, without the slowdown in required spending levels. From a strategic perspective, the intensity of investments in public agricultural research requires equal conditions when facing the main international competitors. Developed countries invest around 3.12% of agricultural GDP in public research (Heisey; Fuglie 2018). Brazil invested approximately 1.8% of its agricultural GDP in research, mostly public, until 2013 (Martha Júnior; Alves, 2018). There was a reduction in this level of investment with the recession between 2015-2017, which added to the weak economic recovery in the following years. Two relevant consequences arise from this reflection: a) the need to increase investments in public agricultural research in the country in order to guarantee the continuity of the virtuous cycle of innovation in the agricultural sector; b) the need to encourage engagement of the private sector, as governmental contribution alone, even if increased, will not be enough to sustain the required levels of investment in research for a competitive agriculture in the coming decades.

Last, but not least, the implementation of successful strategies by the private and public sectors, and the design of public policies with greater impact on the competitiveness and sustainability of Brazilian agricultural production, require adequate assessment tools to provide credible and verifiable analyses of the technical-economic-environmental-social dimensions. Without a robust understanding of these dimensions, strategies, policies, programs and, ultimately, the associated decision-making may prove inappropriate and impractical, with unintended consequences (outcomes). In this context, digital agriculture approaches, which make use of large databases (Big Data), advanced models and modeling techniques (artificial intelligence, analytics), in different areas of knowledge, are of great relevance to support the decision-making process at its different levels.

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