IMPACTO CIENTÍFICO
EDITORA

# CHALLENGES AND OPPORTUNITIES OF DIGITAL AGRICULTURE IN PROMOTING SUSTAINABILITY AND SOCIAL INCLUSION AMONG SMALL-SCALE FARMERS IN BRAZIL

# DESAFIOS E OPORTUNIDADES DA AGRICULTURA DIGITAL NA PROMOÇÃO DA SUSTENTABILIDADE E DA INCLUSÃO SOCIAL ENTRE OS PEQUENOS PRODUTORES NO BRASIL

# DESAFÍOS Y OPORTUNIDADES DE LA AGRICULTURA DIGITAL PARA PROMOVER LA SOSTENIBILIDAD Y LA INCLUSIÓN SOCIAL DE LOS PEQUEÑOS PRODUCTORES EN BRASIL

https://doi.org/10.56238/edimpacto2025.080-007

**Geraldo Antônio da Cruz Neto[1], Carolina Merida[2], Murilo Couto Lacerda[3], Rejaine Silva Guimarães[4], Patrícia Spagnolo Parise Costa[5], Línia Dayana Lopes Machado[6]**

## ABSTRACT

The article analyzes how digital agriculture, or smart agriculture, can simultaneously enhance environmental sustainability and promote social inclusion among small rural producers in Brazil. It argues that technologies such as sensors, IoT, big data and cloud computing make it possible to optimize input use, reduce waste, monitor climate conditions and increase productivity with lower environmental impact. However, it shows that these benefits are unevenly distributed due to low connectivity in rural areas, the high cost of equipment and regional asymmetries in income and infrastructure. Data from the 2017 Agricultural Census indicate that more than 70% of farms did not have internet access, which limits the use of management applications, marketing platforms and remote technical assistance. This scenario is compounded by low levels of schooling and digital literacy among most producers, which hinders the appropriation of these technologies. The article also examines the Climate-Smart Agriculture (CSA) agenda, highlighting its potential to integrate productivity, climate adaptation and emissions mitigation, while warning of the risk of excluding small producers when policies and programs privilege large enterprises. It concludes that digital agriculture will only become an effective driver of sustainability and inclusion if it is articulated with robust

[1] Master's student in Agribusiness and Development Law. Universidade de Rio Verde.
E-mail: geraldocruz@unirv.edu.br Orcid: https://orcid.org/0009-0001-8102-1289
Lattes: http://lattes.cnpq.br/3215741296289502
[2] Dr. Universidade de Rio Verde. E-mail: merida@unirv.edu.br
Orcid: https://orcid.org/0000-0002-5546-5660 Lattes: http://lattes.cnpq.br/4407767690530183
[3] Dr. Universidade de Rio Verde. E-mail: murilo.couto@unirv.edu.br
Orcid: https://orcid.org/0000-0003-4484-0899 Lattes: http://lattes.cnpq.br/9851155183694726
[4] Dr. Universidade de Rio Verde. E-mail: rejaine@unirv.edu.br
Orcid: 0000- 0003-3264-4233 Lattes: http://lattes.cnpq.br/2926559239072928
[5] Dr. Universidade de Rio Verde. E-mail: parise@unirv.edu,br
Orcid: 0000-0002-2427-4933 Lattes: http://lattes.cnpq.br/0855847967155495
[6] Dr. Universidade de Rio Verde. E-mail: liniadayana@yahoo.com.br
Orcid: https://orcid.org/0000-0002-4346-824X Lattes: http://lattes.cnpq.br/2642744874617998

policies for connectivity, training, rural extension and social participation, guided by socio-environmental justice.

**Keywords:** Digital Agriculture. Social Inclusion. Sustainability. Rural Producer. Small-Scale Farmer.

## RESUMO

O artigo analisa como a agricultura digital ou agricultura inteligente pode, ao mesmo tempo, potencializar a sustentabilidade ambiental e promover inclusão social entre pequenos produtores rurais no Brasil. Discute-se que tecnologias como sensores, IoT, big data e computação em nuvem permitem otimizar o uso de insumos, reduzir desperdícios, monitorar clima e elevar a produtividade com menor impacto ambiental. Contudo, evidencia-se que esses benefícios são desigualmente distribuídos, em razão da baixa conectividade no meio rural, do alto custo de equipamentos e das assimetrias regionais de renda e infraestrutura. Os dados do Censo Agro 2017 mostram que mais de 70% dos estabelecimentos não tinham acesso à internet, o que limita o uso de aplicativos de gestão, plataformas de comercialização e assistência técnica remota. Soma-se a isso o baixo nível de escolaridade e de alfabetização digital da maioria dos produtores, o que dificulta a apropriação das tecnologias. O trabalho também examina a agenda da agricultura inteligente para o clima (CSA), apontando seu potencial para integrar produtividade, adaptação climática e mitigação de emissões, mas alertando para o risco de exclusão de pequenos produtores quando políticas e programas privilegiam grandes empreendimentos. Conclui-se que a agricultura digital só se tornará vetor efetivo de sustentabilidade e inclusão se articulada a políticas robustas de conectividade, formação, extensão rural e participação social, orientadas por justiça socioambiental.

**Palavras-chave:** Agricultura Digital. Inclusão Social. Sustentabilidade. Produtor Rural. Pequeno Produtor.

## RESUMEN

Este artículo analiza cómo la agricultura digital, o agricultura inteligente, puede mejorar simultáneamente la sostenibilidad ambiental y promover la inclusión social entre los pequeños productores rurales de Brasil. Argumenta que tecnologías como sensores, IoT, big data y computación en la nube permiten optimizar el uso de insumos, reducir el desperdicio, monitorear el clima y aumentar la productividad con un menor impacto ambiental. Sin embargo, destaca que estos beneficios se distribuyen de manera desigual debido a la baja conectividad en las zonas rurales, el alto costo de los equipos y las disparidades regionales de ingresos e infraestructura. Los datos del Censo Agropecuario de 2017 muestran que más del 70% de las fincas carecían de acceso a internet, lo que limitaba el uso de aplicaciones de gestión, plataformas de comercialización y asistencia técnica remota. A esto se suma el bajo nivel de educación y alfabetización digital de la mayoría de los productores, lo que dificulta la adopción de estas tecnologías. Este trabajo también examina la agenda de la agricultura climáticamente inteligente (CSA), destacando su potencial para integrar la productividad, la adaptación climática y la mitigación de emisiones, pero advirtiendo sobre el riesgo de excluir a los pequeños productores cuando las políticas y los programas favorecen a las grandes empresas. Se concluye que la agricultura digital solo se convertirá en un vector eficaz de sostenibilidad e inclusión si se articula con políticas sólidas de conectividad, capacitación, extensión rural y participación social, guiadas por la justicia socioambiental.

**Palabras clave:** Agricultura Digital. Inclusión Social. Sostenibilidad. Productor Rural. Pequeño Productor.

## 1 INTRODUCTION

The intensification of food production in recent decades has been increasingly supported by technological innovations capable of increasing productivity, reducing losses and mitigating environmental impacts. In this scenario, the so-called digital agriculture or agriculture 4.0 emerges as a set of solutions based on sensors, internet of things (IoT), global positioning systems, cloud data analysis, and automation, which promise to profoundly transform the ways of producing, managing, and marketing in the field. In addition to increasing efficiency in the use of inputs and natural resources, such technologies are often presented as instruments capable of contributing to environmental sustainability and food security, in line with the global agenda for combating climate change and promoting sustainable development.

However, the diffusion of these technologies does not occur in a social vacuum. The Brazilian countryside is marked by strong power asymmetries, land concentration, income inequalities, and large disparities in access to digital infrastructure, especially with regard to quality connectivity, the availability of equipment, and the technical qualification of producers. Small farmers, traditional communities, and historically vulnerable groups run the risk of remaining or even deepening their condition of marginalization if digitalization policies are designed only from the logic of large agribusiness players. Thus, digital agriculture can both open up new opportunities for social inclusion through access to information, markets and services and reinforce existing exclusion, if structural barriers are not adequately addressed.

In this context, the central question that guides this study arises: what are the main challenges and opportunities of digital agriculture in the simultaneous promotion of environmental sustainability and social inclusion in the Brazilian countryside, especially with regard to the reality of small producers? It is based on the hypothesis that digital technologies applied to agriculture have effective potential to optimize the use of natural resources, reduce environmental impacts and increase food security, while favoring the inclusion of small producers in production chains and public policies. However, this potential remains limited by structural obstacles, such as the precariousness of the connection infrastructure, low digital literacy, the insufficient supply of technical assistance and rural extension, and the fragmented design of innovation policies that tend to concentrate the benefits of digital agriculture in the most capitalized segments of agribusiness.

In light of this problem, the general objective of this article is to identify and analyze the main challenges and opportunities of digital agriculture in promoting sustainability and social inclusion in the Brazilian countryside, with an emphasis on the situation of small producers with less access to technological infrastructure. Specifically, it seeks to: (1) present the concept of digital agriculture and its promises in terms of productive efficiency and sustainability; (2) discuss the obstacles related to digital infrastructure, professional qualification and socioeconomic conditions in rural areas; and (3) examine the extent to which the climate-smart agriculture agenda can be appropriate as an opportunity for socio-environmental justice or, conversely, reinforce pre-existing asymmetries.

Methodologically, it is a qualitative research, based on a bibliographic and documentary review on digital agriculture, sustainability, social inclusion and public policies aimed at the rural environment. Studies and documents were selected that address, in an articulated way, the technological, environmental and social dimension of the digitalization of agriculture in the Brazilian context of small producers, allowing the construction of an analytical framework on the risks and potentialities of this transformation. Based on this framework, the article seeks to contribute to the legal and interdisciplinary debate around the need for innovation policies that explicitly consider the reduction of inequalities and the guarantee of rights in the countryside, so that digital agriculture is not restricted to a vector of competitiveness, but effectively becomes an instrument of sustainability and social inclusion.

## 2 CONCEPT OF SMART AGRICULTURE OR 4.0

Digital agriculture, also called smart agriculture or agriculture 4.0, aims to establish an integrated network of information through the development of advanced software and hardware. Agricultural systems tend to be transformed into internet-based services, hosted on cloud servers, capable of articulating different data flows and supporting decision-making in the productive environment.

These systems enable internal communication between agricultural machinery, the control of mobile equipment, data interoperability, integration with open geospatial systems, and the provision of agricultural information storage and processing services. Data is collected through Internet of Things (IoT) sensors, drones, weather information, satellite images, economic indicators, and other online databases (Melgar, 2018).

The so-called Fourth Industrial Revolution is characterized by the convergence of technologies such as the Internet of Things, cloud computing, the Internet of People, the Internet of Services, additive manufacturing, big data, cyber-physical systems, digital security, automation, artificial intelligence, simulation, and modeling (Sordi; Vaz, 2021). This movement has direct repercussions on the field, by incorporating these innovations into agricultural production systems and redefining the way in which the use of land, inputs, and the workforce is planned, executed, and monitored.

Smart agriculture, as it is understood today, has been consolidated since mid-2010, with the evolution and diffusion of various technologies: sensor networks, satellite image processing, cloud-based information technology systems, big data analysis, mobile applications, autonomous machines and tractors, among others. These solutions have progressively been incorporated into machinery and production routines on rural properties, allowing for more accurate monitoring of agricultural and livestock activities (Melgar, 2018).

In this context, smart agriculture integrates information and communication technologies into machines, equipment, and sensors employed in agricultural production systems. Emerging technologies, such as the Internet of Things, big data, and cloud computing, tend to drive this advancement, introducing a greater number of robots, algorithms, and artificial intelligence systems in agriculture (Sordi; Vaz, 2021). In theory, such tools can contribute to a more rational use of inputs, waste reduction, increased productivity, and mitigation of environmental impacts, composing an important vector of sustainability.

The digital transformation in agriculture, with the application of technologies from Industry 4.0, thus becomes essential to face complex challenges, such as producing more food with less use of natural resources and inputs. A range of opportunities opens up to optimize the use of water, fertilizers, and pesticides, improve herd management, and increase the efficiency of the entire production chain, reaching new levels of agricultural productivity and sustainability (Consoline, 2020).

In the Brazilian context, Lopes and Contini (2012) emphasize that the articulation between agriculture, sustainability and technology requires simultaneously recognizing the economic centrality of the sector and the ecological limits imposed by the different biomes. The authors argue that the long-term competitiveness of Brazilian agriculture depends on technological trajectories capable of increasing productivity and, at the same time, reducing pressure on soil, water, and biodiversity, which requires public policies and innovation strategies explicitly guided by sustainability criteria.

It is observed that smart agriculture presents, among its main advantages: (1) increase in the amount of real-time data on crops; (2) remote monitoring and control by farmers; (3) more efficient control of water and other natural resources; (4) improvement of livestock management; (5) more accurate assessment of soil and crops; and (6) increase in agricultural production (Mohamed et al., 2021). These benefits, if properly appropriated, can strengthen both large agro-industrial enterprises and smaller-scale production units.

Thus, it can be seen that the process of digital transformation in rural properties is no longer an option, but a practically inevitable path to make Brazilian agriculture more competitive and with greater added value (Bolfe, 2020). However, for this transformation to effectively contribute to social inclusion in the countryside, it is necessary that digital technologies are not limited to large agribusiness companies, but also reach small rural producers, often located in territories with less infrastructure and greater socioeconomic vulnerability.

When accessible and accompanied by public policies for connectivity, technical training, and specialized assistance, digital agriculture solutions can help small producers reduce costs, better plan the use of inputs, access market information, and expand their insertion in more complex production chains.

On the other hand, the absence of these conditions tends to concentrate the benefits of smart agriculture in the most capitalized segments, deepening inequalities and limiting the potential of digital agriculture as an instrument of sustainability and social inclusion. It is precisely this tension between opportunities and risks that will be explored in the following sections, when examining the challenges of digital infrastructure, professional qualification, and socio-environmental justice in the Brazilian context.

## 3 CHALLENGES FOR DIGITAL INFRASTRUCTURE AND PROFESSIONAL QUALIFICATION

For smart farming to materialize on farms, real-time data processing and transmission are crucial aspects. The effectiveness of the technologies described in the previous section depends directly on the availability of connectivity and a minimum digital infrastructure, without which the benefits associated with sustainability and social inclusion remain only potential (Sordi; Vaz, 2021). However, significant challenges persist in the Brazilian countryside, notably low mobile network coverage in rural areas, the limited supply of high-quality internet, and the cost of access for lower-income producers.

Smart agriculture models require a minimal set of physical devices to collect, store, and transmit data, ranging from smartphones, tablets, sensors, and actuators to computers, servers, and georeferenced machinery. This structural lack is particularly evident in small rural properties. Although there is a gradual reduction in costs and greater diffusion of digital technologies, many farmers do not have the necessary hardware to fully incorporate these practices, due to economic and financial constraints (Sordi; Vaz, 2021). As a result, gains in efficiency and rational use of natural resources tend to be concentrated among more capitalized producers, reproducing inequalities in access to innovation.

In the Brazilian context, this reality is aggravated by data from the 2017 Agricultural Census[7], according to which only 28% of producers declared having access to the internet (1.43 million producers), 659 thousand via broadband and 909 thousand via mobile internet. Consequently, more than 70% of rural establishments – about 3.64 million properties – did not have any form of connection at the time of the survey (BRASIL, 2017).

By analyzing the different Brazilian biomes, Buainain et al. (2018) show that the challenges for sustainable agriculture are not restricted to the adoption of new technologies, but involve deep regional asymmetries in income, infrastructure, and access to public policies. The authors emphasize that the transition to more sustainable production models requires recognizing the heterogeneity of agricultural systems, with particular attention to the conditions of smallholders and family farmers, who face much more severe constraints on credit, technical assistance, and investment capacity.

The absence of connectivity limits the use of management applications, trading platforms, climate monitoring systems, and remote technical assistance tools, restricting precisely those resources that could strengthen productive sustainability and expand the social inclusion of small producers in agro-industrial chains.

Connectivity thus plays a strategic role in improving technical assistance, offering distance education, access to market information and the integration of agricultural machinery and equipment. These functions enhance cost reduction, increased productivity, and the adoption of more efficient and environmentally responsible management practices. Recent reports indicate that connection infrastructure and data interoperability are among the main challenges to integrate Brazilian agriculture into the 4.0 era (São Paulo Research Foundation, 2020), impacting more intensely the segments of smaller production scale (Bolfe, 2020).

In addition to deficiencies in digital infrastructure, professional qualification is another central obstacle to the spread of digital agriculture. The implementation of technologies associated with smart agriculture requires the training of producers, employees, consultants, extension workers and technicians to deal with new production models based on data and the digitalization of processes. Many of these solutions require advanced technical skills to operate interfaces, interpret indicators, and make decisions based on monitoring panels, which contrasts with the levels of education and digital literacy still prevalent in rural Brazil (Sordi; Vaz, 2021).

[7] Data from the 2017 Agricultural Census, the last rural census survey carried out by the IBGE, is used, which remains the most comprehensive and current source of structural information on Brazilian agricultural establishments.

According to the 2017 Census of Agriculture, among approximately five million agricultural producers, 15% declared that they had never attended school, 14% had only reached the level of literacy and 43% had attended at most elementary school. In summary, 73% of the producers have, at most, completed or incomplete elementary school, and 1.1 million (23%) declared that they do not know how to read or write (IBGE, 2017). These data show that low education and educational exclusion constitute significant barriers to the adoption of digital technologies, especially among small producers and family farmers.

In order for farmers to fully realize the potential of smart agriculture, it is essential to strengthen consulting and rural extension services with a focus on digital skills. Consultants, technicians and specialists also need to develop new skills, as they will start working in digitalized and data-driven service environments, playing a mediating role between technological solutions and the concrete needs of rural communities. Interactions between farmers and extension agents tend to be increasingly mediated by remote platforms, which reinforces the importance of specific digital inclusion policies for the field (Sordi; Vaz, 2021).

In view of this scenario, overcoming the deficits in digital infrastructure and professional qualification must be understood as a condition for digital agriculture to become, in fact, a vector of sustainability and social inclusion in Brazilian agribusiness. The articulated action of the public authorities and the private sector, through investments in rural connectivity, continuing education programs, and credit policies aimed at small producers, is essential to prevent digitalization from deepening historical asymmetries. Only with this set of initiatives will it be possible to democratize access to technologies and ensure that the benefits of smart agriculture also reach the most vulnerable segments of the countryside.

## 4 CLIMATE-SMART AGRICULTURE

Climate-Smart Agriculture (CSA) has emerged as an approach aimed at increasing productivity and food security, building resilience to climate change, and reducing greenhouse gas emissions in the agricultural sector (Chandra; Shmelev, 2017). This is a relatively recent concept, systematized and disseminated by the Food and Agriculture Organization of the United Nations (FAO) since 2010, which seeks to articulate, in the same agenda, three central objectives: (1) to sustainably expand food production; (2) strengthen the adaptive capacity of agricultural systems and rural communities; and (3) mitigating the environmental impacts of agricultural activity (Chandra; Shmelev, 2017).

This approach has materialized through the formulation of public policies, financing programs, and management practices that combine technological innovations, organizational changes, and economic instruments. In this context, digital agriculture technologies such as sensors, climate monitoring systems, real-time data analysis, and decision support platforms can play a strategic role in enabling the more efficient use of water, inputs, and energy, as well as the monitoring of climate risks on a fine scale.

Thus, there is a direct interface between the climate-smart agriculture agenda and the agriculture 4.0 solutions discussed in the previous sections, as both rely on data and connectivity to promote environmental sustainability.

However, the critical literature on the subject warns of the risk that climate-smart agriculture is built with an excessive focus on technical and productivist dimensions, underestimating the sociopolitical processes that organize access to land, water, credit, and technologies. Chandra and Shmelev (2017) highlight that, in various contexts, CSA programs tend to marginalize vulnerable groups, such as smallholder farmers and traditional communities, by not adequately incorporating their demands, knowledge, and material conditions. Often, land and water rights, power relations, and social injustices are framed apolitically or simply absent from official climate and agriculture policy objectives, even when it claims to strengthen food security.

This criticism becomes particularly relevant when one observes that many climate-smart agriculture initiatives are financed or influenced by international organizations, large companies and investment funds, whose priorities do not always coincide with the needs of small producers. Credit, loan, and subsidy policies, as well as market-based instruments such as emission reduction and carbon certification programs, can, if poorly designed, predominantly favor larger-scale producers, leaving out family farmers, indigenous peoples, and peasant communities (Chandra and Shmelev, 2017). In such cases, CSA runs the risk of reinforcing historical asymmetries, concentrating economic and technological benefits on already privileged groups and expanding social exclusion in the countryside.

On the other hand, the climate-smart agriculture agenda itself offers a window of opportunity to reposition the concerns of millions of smallholders – men and women – who live in areas of high climate risk and are deprived of justice and equality. Instead of reproducing cycles of marginalization, it is possible to conceive of CSA from a rights-based perspective, in which the fight against climate change is articulated with the recognition of human rights, the democratization of access to digital technologies, and the strengthening of social participation in the formulation of public policies (Chandra and Shmelev, 2017).

In this sense, one of the alternatives is to develop and disseminate climate-smart agriculture practices that incorporate digital technologies as instruments of empowerment and not just control, creating inclusive structures that promote the direct participation of small producers, grassroots organizations, and rural social movements. This implies, for example, providing accessible climate monitoring platforms in understandable languages and interfaces, ensuring connectivity in vulnerable territories, supporting networks of cooperatives that use data to negotiate better marketing conditions, and including family farmers in payment programs for environmental services and climate adaptation.

In a case study on the implementation of digital agriculture in Brazilian agribusiness, Manfredo Neto (2023) shows that the adoption of technologies associated with agriculture 4.0 depends not only on the availability of equipment and connectivity, but also on management, governance, and training arrangements of the teams involved. The author demonstrates that the expected results in terms of efficiency and sustainability tend to be more robust when the introduction of digital tools is planned in an integrated way, considering the reality of the different profiles of producers, including those on a smaller scale, and incorporating mechanisms for monitoring and continuous evaluation.

In this way, "smart" agricultural practices and scientific investments can be oriented towards deeper changes, optimizing economic, social and environmental benefits, without losing sight of social inclusion as a structuring axis. Articulated with the discussions on digital infrastructure and professional training presented in the previous section, climate-smart agriculture will only become an effective instrument of socio-environmental justice if its policies and projects are designed to reduce inequalities, guarantee rights, and amplify the voice of small producers in climate governance and rural development.

## 5 FINAL CONSIDERATIONS

This article aimed to **identify and analyze the main challenges and opportunities of digital agriculture in promoting sustainability and social inclusion among small producers in Brazil,** based on a literature and documentary review on agriculture 4.0, digital infrastructure, professional qualification and climate-smart agriculture.

It was based on the hypothesis that digital technologies have effective potential to optimize the use of natural resources, reduce environmental impacts and increase food security, while at the same time they could favor the inclusion of small producers in production chains and public policies, as long as they are accompanied by adequate material and institutional conditions.

The analysis of the contributions on **digital agriculture or agriculture 4.0** highlighted a wide set of **opportunities** related to the use of sensors, Internet of Things, cloud computing, big data, and decision support systems. These technologies allow monitoring crops, soils, herds, and weather conditions in real time, contributing to a more rational use of inputs, reducing waste, increasing productivity, and mitigating environmental impacts, configuring an important vector of **sustainability.**

However, the results also demonstrate that such opportunities are not homogeneously distributed in the Brazilian countryside. Low **internet coverage**, limited supply of broadband services, and the high cost of digital equipment constitute relevant barriers, especially for small producers and family farmers. More than 70% of rural establishments did not have any form of internet connection in the 2017 Census of Agriculture, which restricts the use of management applications, marketing platforms, climate monitoring systems and remote technical assistance tools.

To this picture are added the challenges of **professional qualification.** Data from the Census of Agriculture indicate that most producers have at most elementary education and a significant portion declare that they do not know how to read or write, which highlights the magnitude of the educational barriers to the adoption of data-based digital technologies.

Thus, smart agriculture tends to be appropriated primarily by more capitalized segments of agribusiness, reproducing inequalities in access to innovation and limiting the potential for **social inclusion** associated with digitalization.

In the field of climate policies, the Climate-Smart Agriculture (CSA) agenda reinforces both the promises and tensions of digitalization. On the one hand, CSA seeks to articulate increased productivity, adaptation to climate change and emission reduction, being supported by digital technologies that enable more efficient monitoring and management of production systems. On the other hand, the critical literature warns of the risk that programs and financial instruments linked to the CSA mainly favor large producers, marginalizing small farmers, traditional communities and indigenous peoples, when they do not adequately incorporate their rights, knowledge and needs.

In view of this set of evidence, the **initial hypothesis is only partially confirmed.** Digital agriculture and climate-smart agriculture do not in themselves guarantee sustainability and social inclusion. They do indeed offer a wide range of opportunities, but their realization depends on **political choices** and the design of institutions that explicitly address the inequalities in infrastructure, income, schooling, and access to rights that mark the Brazilian countryside. Without these conditions, digitalization tends to deepen historical asymmetries, concentrating benefits on already privileged groups and expanding the exclusion of small producers.

It is concluded, therefore, that digital agriculture can become an important instrument of **environmental sustainability and social inclusion**, as long as it is articulated with robust public policies for rural connectivity, digital training and literacy programs, strengthening of technical assistance and rural extension, and mechanisms for the participation of small producers in the formulation and governance of innovation and climate agendas. Only from this perspective guided by principles of **socio-environmental justice** and democratization of access to technologies will it be possible to make agriculture 4.0 transcend the strict logic of competitiveness and become an effective vector for reducing inequalities in rural areas.

Finally, the results systematized here suggest the need for **new empirical studies** on concrete experiences of adoption of digital technologies by small producers, cooperatives and community-based initiatives, as well as legal investigations on regulation, data protection and safeguarding rights in the context of digital agriculture. The continuity of this debate, from an interdisciplinary perspective, is essential to guide innovation policies that are aligned with a truly sustainable, inclusive rural development project committed to rural subjects.

## REFERENCES

Bolfe, É. L. (2020). Desafios, tendências e oportunidades em agricultura digital no Brasil. In É. L. Bolfe (Ed.), Agricultura digital: Pesquisa, desenvolvimento e inovação nas cadeias produtivas (pp. 380–406). Embrapa. https://www.alice.cnptia.embrapa.br/alice/handle/doc/1126283

Buainain, A. M., Alves, E., Silva, J. A., & Souza, Z. (2018). Desafios para uma agricultura sustentável: Abordagem baseada nos biomas brasileiros. Desenvolvimento em Debate, 6(2), 71–97. https://revistas.ufrj.br/index.php/dd/issue/view/1393

Chandra, A., & McNamara, K. E. (2017). The relevance of political ecology perspectives for smallholder Climate-Smart Agriculture: A review. Journal of Political Ecology, 24(1), 821–842. https://doi.org/10.2458/v24i1.20969

Consoline, L. (2020). Desafios, problemas e oportunidades da inovação na agricultura no Brasil [Trabalho de Conclusão de Curso de graduação, Universidade Estadual de Campinas]. Repositório Institucional da Unicamp. https://repositorio.unicamp.br/Resultado/Listar?guid=42a2867a65eca1d26033

Instituto Brasileiro de Geografia e Estatística. (2017). Censo Agro 2017: Resultados definitivos. IBGE. https://biblioteca.ibge.gov.br/visualizacao/periodicos/3096/agro_2017_resultados_definitivos.pdf

Lopes, M. A., & Contini, E. (2012). Agricultura, sustentabilidade e tecnologia. Agroanalysis, 32(2). https://ainfo.cnptia.embrapa.br/digital/bitstream/item/132991/1/Agricultura-Sustentabilidade-e-Tecnologia.pdf

Manfredo Neto, L. (2023). Perspectiva, implementação, gestão e tecnologias da agricultura digital: Um estudo de caso aplicado ao agronegócio brasileiro [Dissertação de mestrado, Universidade Federal de São Carlos]. Repositório UFSCar. https://repositorio.ufscar.br/handle/ufscar/18165

Melgar, M. (2018). Agricultura digital ou agricultura 4.0. Memoria Presentación de Resultados de Investigación 2017-2018, 16(01), 12–18. https://cengicana.org/publicaciones

Mohamed, E. S., Belal, A. A., Abd-Elmabod, S. K., El-Shirbeny, M. A., Gad, A., & Zahran, M. B. (2021). Smart farming for improving agricultural management. The Egyptian Journal of Remote Sensing and Space Sciences, 24(3), 971–981. https://doi.org/10.1016/j.ejrs.2021.08.007

Soler-Tovar, D. (2017). Conceptualización y necesidades de una agricultura climáticamente inteligente. Revista de Medicina Veterinaria, (33), 7–11. http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0122-93542017000100007

Sordi, V. F., & Vaz, S. C. M. (2021). Os principais desafios para a popularização de práticas inovadoras de agricultura inteligente. Desenvolvimento em Questão, 19(54), 204–217. https://doi.org/10.21527/2237-6453.2021.54.204-217