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AGRICULTURE 6.0: A NEW PROPOSAL FOR THE FUTURE OF AGRIBUSINESS

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ABSTRACT

Objective: The purpose of the research is to understand the technological evolution of agriculture over the years and propose a new perspective for the practices that are becoming established in agribusiness.

Theoretical framework: The study analyzes agricultural activities practiced from the beginning of agriculture up to the present day to demonstrate the trends that are likely to gain strength in this sector in the coming years.

Method: The investigation aimed to be descriptive. Bibliographic and documentary research were used as methodological procedures.

Results and conclusion: The findings suggest that the agribusiness sector is transitioning into a novel phase termed Agriculture 6.0, wherein sustainability assumes a pivotal role in business advancement. A paradigmatic shift is observed in production processes, characterized by an ongoing pursuit of ecosystem preservation and restoration, in congruence with the aspirations of future generations for an improved quality of life.

Research implications: The proposal of a new technological model that characterizes the evolution of agricultural activities is focused on defining concepts, systems, technologies/services, and areas of study. This enables agribusiness organizations to gain a deeper understanding of the transformations occurring in the macro-environment, thereby considering these aspects in their planning processes.

Originality/value: Brazil is one of the world's largest agricultural producers and exporters. Therefore, in order to continue solidifying itself as a sustainable supplier of food, fibers, and other agricultural products, the country needs to remain attentive to the changes demanded by the environment and the trends that are gaining strength in the current scenario.

Keywords: Agriculture 6.0, Technological Evolution, Sustainability, Agribusiness, Trends.

AGRICULTURA 6.0: UMA NOVA PROPOSTA PARA O FUTURO DO AGRONEGÓCIO

RESUMO

Objetivo: O propósito da pesquisa é entender a evolução tecnológica da agricultura ao longo dos anos e propor uma nova visão para as práticas que estão se consolidando no agronegócio.

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Referencial teórico: O estudo analisa as atividades agrícolas praticadas desde o início da agricultura até os dias atuais em função de mostrar quais são as tendências que devem ganhar força nesse setor nos próximos anos.

Método: A investigação possui teor descritivo. Pesquisas bibliográficas e documentais foram utilizadas como procedimentos metodológicos.

Resultados e conclusão: Os resultados sugerem que o agronegócio está entrando em uma nova era, chamada agricultura 6.0, que coloca a sustentabilidade no centro do desenvolvimento dos negócios. Há uma mudança de paradigma na forma de produzir com uma busca incessante pela preservação e recuperação dos ecossistemas, em linha com o que as gerações futuras almejam para uma melhor qualidade de vida.

Implicações da pesquisa: A proposta de um novo modelo tecnológico que caracterize a evolução da atividade agropecuária tem como foco a definição dos conceitos, sistemas, tecnologias/serviços e áreas de estudo, para que organizações do agronegócio possam compreender melhor as transformações que têm acontecido no macroambiente para considerar estes aspectos em seu processo de planejamento.

Originalidade/valor: O Brasil é um dos maiores produtores e exportadores agrícolas do mundo. Dessa forma, para continuar se consolidando como fornecedor sustentável de alimentos, fibras e outros agro-produtos, o país precisa estar atento às mudanças que o ambiente exige e as tendências que se fortalecem à luz do contexto atual.

Palavras-chave: Agricultura 6.0, Evolução Tecnológica, Sustentabilidade, Agronegócios, Tendências.

1 INTRODUCTION

For a long time, human interventions in the environment have brought negative impacts on global ecosystems. However, since more than half of the world's economic production depends on nature, this dynamic's continuity can result in unprecedented consequences (Heading & Zahidi, 2023). The implementation of processes aimed only at maximising production, without considering the depletion of nature, ended up threatening economic development. For this reason, the economy and ecology should walk side by side in decision-making and policy design for society growth (Venkatesan et al., 2021).

Currently, the population's desire for increasingly sustainable practices is clear. The environment becomes more critical for consumers, who seek ecologically correct choices to the detriment of traditional purchases without social and environmental responsibility. This perspective has led to the beginning of a green conscience, translated into a conscious consumption that appreciates the form of production and the impacts caused in nature and society (Bulut et al., 2021).

The growing concern with these issues is bringing essential transformations to the productive models through the rise of disruptive solutions for global agriculture and livestock (Embrapa, 2021). New production methods based on actions that protect nature and animal and human health come from a historical demand and are becoming increasingly relevant (Vidal et al., 2021).

Over time, there was a natural transition from traditional technologies focused on momentary economic gains, without concern of the consequences and damage caused to the environment - named "grey" - to strategies based on nature with rational use of natural resources - called "green" (Gusev, 2020). In this sense, businesses start from an integrated vision of the environment and production, positively impacting the competitiveness, safety, efficiency and sustainability of the food, energy, and other agro-product chains.

Brazil has stood out in this context due to its significant agricultural and livestock production results. The intensive use of technologies allows produce more with less through systems that seek increased productivity with reduced costs and adopting sustainable practices (Neves, 2016). Since agribusiness is one of the main pillars that drive our country's development, this sector represents a massive opportunity for Brazil to consolidate itself in sustainable development and to stand out for its production potential with balance between productivity, preservation and even revitalisation of the environment.

Like any other sector, agriculture and its practices need to be constantly changing to adapt to the new propositions that the macroenvironment requires, due to the challenges of meeting the demand of a growing global population, besides managing the rational use of natural resources and mitigating climate change (Hatanaka et al., 2021).

Agribusiness and developing an increasingly sustainable economy are inseparable guidelines. Considering this, it is essential to understand the agricultural technological evolution over the years and identify the following trends that will lead us to a more productive and ecological path. Given these issues, the purpose of this article is to present a new proposal for the future of agribusiness, Agriculture 6.0, marked precisely by the integration of various actions and good practices that will continue to lead Brazil to successful results, whether in the productive, environmental, social, or economic sphere.

2 METHOD

The research holds a descriptive nature, as it analyzes the technological evolution of agriculture and proposes a new model to characterize trends that are being identified as promising for the future of agribusiness. The study encompassed bibliographic research of scientific articles within the 'Scopus' and 'Google Scholar' databases, as well as documentary retrieval of information from reports and databases of esteemed entities in the agricultural sector.

3 THEORETICAL FRAMEWORK

Agricultural practices began with Agriculture 1.0, characterised by rudimentary and traditional methods with intensive use of labour and animal power. At that time, which lasted until just before the 1950s, the focus was on supplying the local population, and the tools used were simple, leading to a low rate of productivity (Zhai et al., 2020).

Moving to Agriculture 2.0, the modernisation of agriculture triggered by the "Green Revolution" began to advance with the insertion of agricultural machinery. This period was marked by a significant increase in the efficiency of activities from the development of science. New technologies, synthetic inputs and chemical pesticides were created to large-scale production and to reduce vulnerability to natural conditions (Zhai et al., 2020).

On the other hand, the intensive use of this technological package aimed at increasing crop production and productivity has raised reflections on the economic, social and environmental consequences. The exacerbated exploitation of natural resources aggravated groundwater and surface water pollution, increased soil erosion and transformed the landscapes with a loss of cultural, heritage and tourism values (ZANONI, 2004).

Agriculture 3.0 emerged from the development of computers and electronics. Agricultural machinery that used to be operated manually started incorporating GPS signals, bringing greater efficiency to operations. The strategies adopted in this stage began to curb the problems that arose in the previous one since this precision agriculture model reduced the need for chemicals and optimised irrigation systems (Zhai et al., 2020).

Data is now used to monitor agricultural activities and outcomes through the information that considers the variations within farms. In addition, remote sensing technologies and farm guidance systems are adopted to optimise processes and save resources, as it deepens the level of detail of needs in the field (Cema, 2017).

The transition to Agriculture 4.0 is characterised by the evolution of various digital technologies such as sensor networks, Internet of Things (IoT), drones, software systems, satellite image processing, cloud computing, extensive data analysis and mobile applications (Zambon et al., 2019).

This phase is marked by data collection, processing and analysis to provide diagnostics to make producers decisions more assertive and strategic (Saiz-Rubio & Rovira-Más, 2020). Creating a digital ecosystem with real-time management brings greater efficiency to the entire agribusiness chain, from production, processing and distribution to the final consumer (Liu et al., 2020).

The operations become an integrated network of internal and external actions, centralising data to associate various systems and agents along the production chain. In addition, implementing these technologies becomes more accessible to producers with cheaper and improved sensors, low-cost processors and high-range cellular communication (Cema, 2017; Maffezzoli et al., 2022).

The next step came with Agriculture 5.0, which relies on its production processes using robotics, autonomous decision systems, wireless sensor networks, crewless vehicles, machine learning and artificial intelligence algorithms. Known as smart agriculture, it introduces solutions that refine data analysis through an improved understanding of accurate, relevant and reliable information (Ahmad & Nabi, 2021).

Table 1. Summary table with the evolution of the types of agriculture and their practices.

Type of Agriculture	Definition	Period	Practices	Impacts / Changes	Sources
Agriculture 1.0 Traditional agriculture	Rudimentary and traditional practices.	Before 1950	Intensive human and animal labor and use of simple tools.	Low Production.	Cema (2017), Zhai et al., (2020).
Agriculture 2.0 Mechanized agriculture	Start of modernization and improvements in agricultural practices.	1950 - 1990	Science, supply of inputs and pesticides, machines and implements, connection to new markets.	Increased efficiency and productivity, scale production. However, it resulted in field chemical contamination, excessive energy consumption and excessive use of natural resources.	Cema (2017), Zhai et al., (2020).
Agriculture 3.0 Precision agriculture	Agricultural guidance systems and productivity monitoring.	1990 - 2015	Agricultural georeferencing, biotechnologies, management per m^2.	Reduced use of chemicals, improved accuracy of activities.	Cema (2017), Zhai et al., (2020).
Agriculture 4.0 Digital agriculture	Development of new data-based digital skills that connect the production model and the different agents in the value chain.	2015 – current	Equipment and digital tools to carry out activities through the collection, integration and analysis of data from the field: IoT, big data, cloud computing, image processing, geographic information system (GIS), drones, communication technologies, blockchain.	Evolution from a traditional system to a digital system reducing time, costs, land use and increasing productivity and production quality.	Cema (2017), Zhai et al., (2020), Saiz-Rubio & Rovira-Más (2020), Liu et al., (2020), Maffezzoli et al., (2022).
Agriculture 5.0 Smart farming	Data-driven properties embedding robotics with AI algorithms into their systems to automate tasks.	Current days	Intelligent systems involving unmanned and autonomous decision support operations: robotics and AI – decision automation; machine learning (ML); wireless sensor networks (WSN).	Solutions that refine decision making, increase profitability and help with labor shortages. In addition to enabling even more precise applications of inputs, they enable greater efficiency in water use and increase yield.	Saiz-Rubio & Rovira-Más, Ahmad & Nabi (2021).

Source: Elaborated by the authors (2023).

Thus, using these modern technologies reduces risks in the field, increases the sustainability of agricultural practices and provides predictive scenarios to the farmer, making agriculture increasingly productive, profitable, and environmentally friendly. Also, agrarian robots encompass the central problem of a labour shortage that farms have been facing (Saiz-Rubio, Rovira-Más, 2020).

4 RESULTS AND DISCUSSION

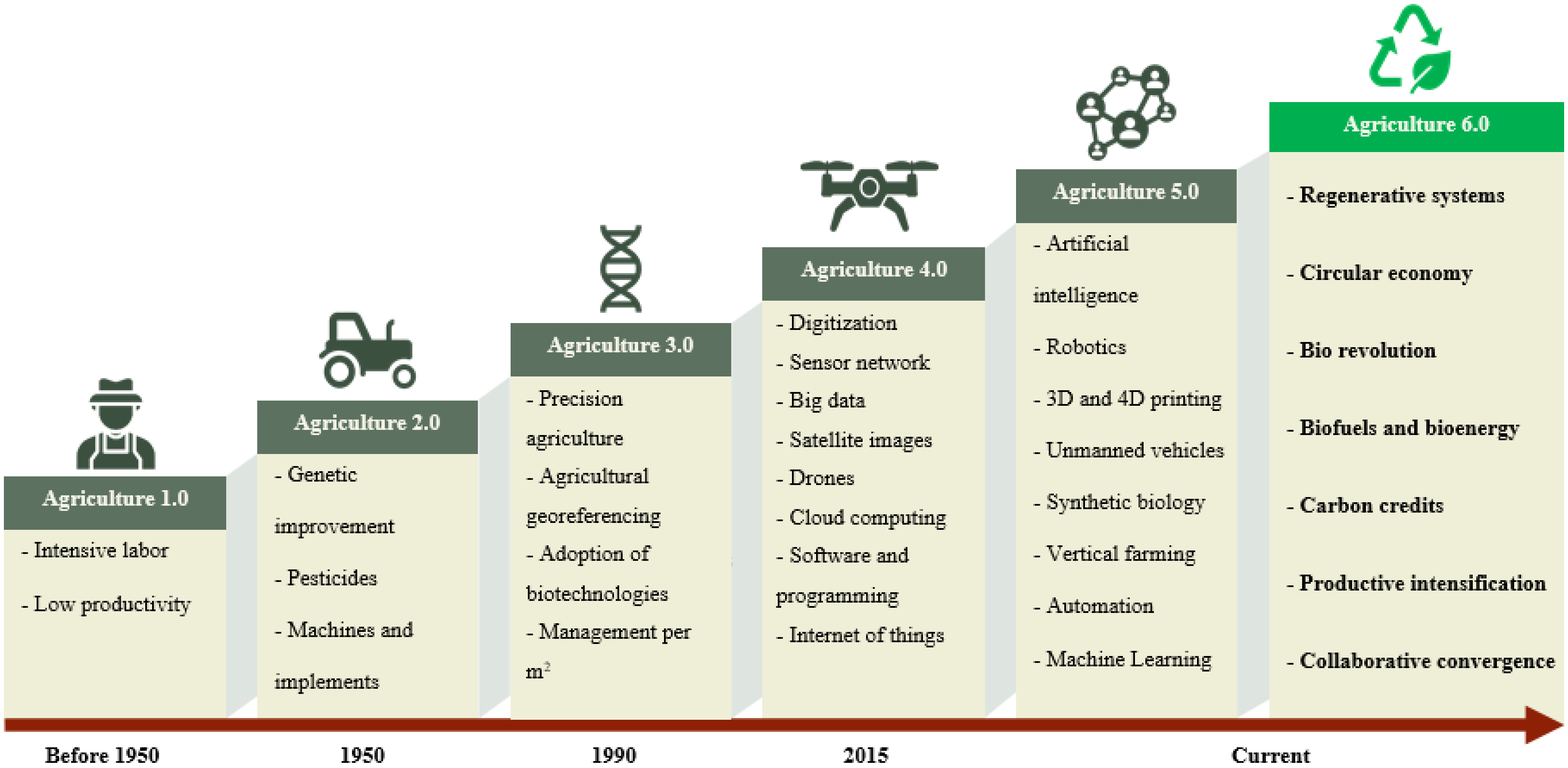
Another era is currently being consolidated in agricultural technological evolution. Agriculture 6.0 strengthens the desire for sustainable development and the increasingly rational use of the planet's resources to leave a natural heritage worthy of future generations. In the coming years, the relationship between man, agriculture and nature will be a crucial issue to prevail the harmony between all existing life forms.

Table 2. A new proposal for the future of agribusiness - Agriculture 6.0.

Type of Agriculture	Definition	Period	Practices	Impacts / Changes	Sources
Agriculture 6.0 Integrative agriculture	Specialized solutions based on nature to protect, manage and restore ecosystems in order to increase the response of productive environments and make them healthier.	Future	Regenerative systems Circular economy Bio revolution Biofuels and bioenergy Carbon credits Productive intensification Collaborative convergence	More resilient production model with rational and sustainable use of natural resources while simultaneously increase human well-being.	Schattman et al., (2023); Massruhá et al., (2020).

Source: Elaborated by the authors (2023).

Thus, this proposal sees such integration as central to defining what lies ahead in agribusiness. The solutions are specialised and nature-based to protect, manage and restore ecosystems. In this sense, the practices seek to increase the responsiveness of productive environments and make them healthier to simultaneously provide human well-being, environmental balance and biodiversity benefits.



Picture 1. The technological evolution of agriculture throughout history.
Source: Elaborated by the authors (2023).

Picture 1 above illustrates the main topics that comprise the "Agriculture 6.0" proposal, comparing it with previous models and their respective processes and technologies incorporated into agricultural and livestock production systems and other links in the production chain. It is worth noting that the technologies that emerged in previous phases must continue to be improved, especially the intelligent tools provided by Agriculture 5.0, but aimed at enhancing the integrative and increasingly sustainable systems of Agriculture 6.0.

The seven main trends that should be strengthened in the coming years will be described below. The use of these technologies may further consolidate Brazilian agribusiness as a sustainable global supplier of food, fibres, bioenergy and other agro-products.

4.1 Regenerative Systems

Given the great need for transformation around the production systems to achieve the planet's sustainability goals due to climate change, regenerative practices have been widely accepted in the last few years. The integrated techniques to be adopted bring measures to increase soil health, sequester carbon from the atmosphere, maintain water quality, conserve and expand biodiversity and improve quality of life (TNC, 2020).

Regenerative agriculture has the potential to produce nutritious food for the growing world population and yet reduce the impact of human actions on the ecosystem. This production model enables the restoration of the environment, making agriculture a solution to environmental problems rather than the villain as it is defined today (Schattman et al, 2023).

The concept encompasses various agricultural techniques that are based on the conscious management of production. One example is cropping rotation or succession of more than one plant species in the same area, being an essential pillar for the improvement of biodiversity, besides reducing the impacts caused by monoculture, such as physical, chemical and biological degradation of the soil and the development of pests (LAL, 2020).

In addition, the adoption of the no-till farming system in straw and the minimum soil disturbance - that is, covering the crop all year round so that the land does not lie fallow during the off-season - helps prevent soil erosion, increases water retention and ends up reducing the levels of atmospheric CO_2 (Giller et al., 2021).

Another practice is the integrated pest management with the introduction of biological products instead of exclusive chemical use. These bio-inputs can help maintain the plants' health by controlling pests and insects that transmit diseases. Besides, these products increase beneficial microorganisms that promote the release, transfer and cycling of essential nutrients from the soil to the plant (Giller et al., 2021).

Integrated production systems with the combination of agricultural, livestock and forestry production systems within the same area can also be considered. They naturally stimulate plant development, increase soil fertility, contribute to the biodiversity of insects and plants, and increase carbon sequestration by the system (Giller et al. 2021).

This issue will be in significant evidence in the coming years all over the planet. Regenerative agriculture is an essential ally to the natural balance of healthy soils, which will help farmers to produce more diversified food with high productivity, safety and quality. Promoting these systems enables a more harmonious relationship between individuals, nature, and the different areas of human activity.

4.2 Circular Economy

The circular economy visualises the productive systems cyclically and add value to products by reducing waste and replacing disposal with reuse flows (Kristoffersen et al., 2021). This practice emerges as a strategy that makes possible to improve economic performance and minimise the damage caused by reducing the use of resources and waste disposal (Velasco-Muñoz et al., 2022).

This production model is a critical path to be followed in agribusiness since it transforms what would previously be discarded in the environment into new products with added value, such as biofertilisers, bioenergy and biomolecules. The principles aim to implement restorative activities since it allows the maintenance of materials already used, by-products or waste for various purposes. Rethinking the linearity usually occurring in production systems is urgent and necessary for environmental preservation and long-term economic growth (Aznar-Sánchez, 2020).

Circular economy practices have primary effects across various business domains, including cost management, supply chain, quality control, environmental management, process optimization, logistics, service management, and research and development. Embracing circularity principles within strategic planning is imperative for organizations, enabling them to attain economically sustainable outcomes while concurrently mitigating environmental and societal impacts (Barros et al., 2021).

4.3 Bio Revolution

The biological sciences represent another essential pillar for the reinvention of new solutions to the challenges that currently plague production systems. Global problems are already being graced with advances in biotechnology, synthetic biology, plant, animal and microbial genomics and phenomics studies, gene editing, development of biomolecules, bio-inserts and other biosystems (Chui et al., 2023).

Bioeconomy is a term that encompasses these various facets. The most influential perspectives involve bioecology, biotechnology, and bioresources (or bio-inputs). The first is based on social changes that alter production models, consumer habits, and even modern culture to prioritize the conscious use of natural resources, biodiversity, and a harmonious relationship between humans and the environment. On the other hand, the biotechnology perspective refers to advances in research and development in areas such as biological science, biochemistry, biophysics, genetics, and nanotechnology. Nature ceases to be consumed and starts to serve as the foundation for the creation of goods and services (Vargas, Pinto & Lima, 2023).

Synthetic biology techniques with increasingly efficient molecular tools (such as CRISPR) are opening many technological opportunities beyond the development of new cultivars and breeds. This biological niche can potentially cause transformative changes for agriculture in the short, medium and long term, bringing more productivity and sustainability (Goold et al., 2018). With the help of genetic engineering, it is possible to redesign existing models in nature to exert different and desirable competencies. These solutions will expand the knowledge about the biological functions of organisms to create new biotechnological products that will bring cost and resource reduction, besides improving the efficiency of plants and animals (Embrapa, 2021).

Finally, bioresources or bio-inputs come to complement fossil-based chemicals with biological ones. There is a growing demand for research on multifunctional microorganisms that positively impacts the field's most diverse needs. Given this, it is worth noting that they will be prominent tools in improving the quality and productivity of agricultural systems and the adaptation of crops to climate change (Gómez-Godínez et al., 2021).

In this sense, bio-inputs are configured as an essential perspective factor with its various contributions for: increase root growth, allowing better absorption of available water by plants; improvement of physical and chemical soil attributes; decreased use of synthetic fertilisers based on nitrogen (N), phosphorus (P) and potassium (K), either by the contribution of nutrients by microorganisms, as by the increased efficiency of nutrient absorption by plants; induction of the plant's defence system and biological control of pests and diseases, also reducing the need for chemical pesticides (MAPA, 2021).

Advances in biological sciences are a bet for future agriculture and represent a new production perspective. Incorporating these biological solutions can deliver quality products with safety and economic viability while offering the potential to restore what has been consumed in previous processes.

4.4 Biofuels and Bioenergy

Producing bioenergy from sugarcane represents a viable and sustainable approach to combatting climate change. To achieve this, various strategies are employed, such as adopting sustainable land use and management practices to enhance soil carbon sequestration, engaging in large-scale production of biofuels, bioelectricity and bioproducts, recycling industrial waste, and implementing sector-specific policies that reward farmers with carbon credits for reducing greenhouse gas emissions (Antar et al., 2021).

It is interesting to highlight the circular economy model that can be obtained when integrating ethanol production from corn and sugarcane, in the so-called "flex full" plants, with cattle raising. This happens because there is a vital co-product in the corn production chain called DDG (Dried Distillers Grains), a protein compound used by the animal industry, which generates manure that can be used as fertiliser for corn and sugarcane (Neves et al., 2021).

Another product that has been gaining prominence in the bioenergy scenario in Brazil is biogas. Produced from the anaerobic decomposition of organic matter, it has as possible raw materials sanitary waste, livestock and agro-industry waste, such as manure and vinasse produced in the sugar cane sector for example (Coelho, 2018).

Due to its characteristic of transforming waste into energy, the biogas chain stands out for its ability to transform "environmental liabilities" into "energy assets". However, biogas only explores 2% of its potential currently. In 2022, the production reached 2.8 billion cubic meters, a growth of 21.3% compared to 2021, but the country can produce approximately 80 billion cubic metres of biogas per year, which would be sufficient to supply all the country's demand for gas sustainably (CiBiogás, 2022).

Several other sustainable products, such as ammonia and green hydrogen, are also produced from the biogas chain (CiBiogás, 2021). Green hydrogen is another fuel that has been much discussed, being referred to by many as the fuel of the future (BEZERRA, 2021). Having an energy capacity of up to three times that of gasoline, green hydrogen is an interesting solution for the country's decarbonisation since it does not emit harmful gases when burned (PAIVA, 2022).

Biomass, which consists of all organic matter of plant or animal origin that can be used for energy generation, is also considered very promising as a renewable and affordable energy source (EPE, 2022). Unlike oil, biomass is a raw material that is not permanently exhausted over time. In addition, its products have a low carbon footprint and do not emit greenhouse gases when burned (TUNA, 2022).

4.5 Carbon Credits

With the purpose of contributing to limit global warming to 1.5°C by 2030, corporations worldwide are setting carbon zero or carbon neutrality (net zero) targets, aiming to eliminate carbon emissions from their operational activities. However, several sectors are still unable to do that due its production processes. This results in most companies relying on the purchase of carbon credits to offset or neutralize the remaining emissions (McKinsey, 2022).

Brazil is at the centre of decarbonization opportunities and its potential has becoming even greater. The country can supply almost half of the global demand for carbon credits by 2030 and the revenue generation potential from carbon credits by the end of the decade reaches US$ 120 billion (ICC Brasil, 2022).

According to McKinsey, the world demand for carbon credits is estimated to grow 15 times by 2030 and up to 100 times by 2050, representing a very promising trend in the next years. Nevertheless, the availability of carbon credits in the Brazilian market is limited, representing less than 1% of the country's annual potential. Furthermore, the country has a remarkable capacity to generate carbon credits since 15% of the global potential for carbon capture through natural means is within its territory (McKinsey, 2022).

Another factor that makes Brazil an attractive location for carbon credit projects is the relatively low cost of developing and implementing such initiatives, as well as its competitiveness compared to the global average. Consequently, the country holds enormous potential to excel in this market, given its abundance of natural resources and ability to provide credits of high quality and integrity (McKinsey, 2022).

4.6 Productive Intensification

Productivity gains in Brazilian agriculture and livestock, together with the growth in demand (domestic and foreign) for the sector's products that should occur in the coming years, are among the main factors to drive our country's growth. In this context, it is essential that strong investments generate technological innovation and infrastructure improvement (Embrapa, 2021).

According to projections, the grain production is expected to grow by over 24% until the 2032/2033 crop season, reaching nearly 390 million tons. Compared to the current production, this represents an increase of 76 million tons, which corresponds to an annual growth rate of over 2%. The increase in productivity will be the decisive factor for achieving this scenario (MAPA, 2023).

The Food and Agriculture Organization of the United Nations (FAO) estimates that 7% of agricultural growth in the world should occur due to intensification and 87% using all productivity gains, with corn and soybean cultures standing out in Brazil. Both the public and the private sectors have developed to encourage agricultural and cattle-raising intensification in Brazil, with the incentive to replace degraded pastures with agriculture and important initiatives such as the new Forest Code, the ABC Plan and the Brazilian INDC (Intended Nationally Determined Contributions), which present the national GHG reduction intentions (Embrapa, 2021).

The incentive for agricultural research and the development of new technologies is essential for Brazil to be competitive in the international market, maintaining its high productivity levels. (Marin et al., 2016). The use of bio-inputs as well as precision agriculture techniques and crop-livestock-forest integration, stand out as tools to improve agricultural efficiency (Embrapa, 2021; Silva, 2021).

4.7 Collaborative Convergence

The continuous and promising technological advancement in the most varied agribusiness fronts requires the use of resources and even the knowledge obtained throughout the process. The path of scientific development should and tends to be convergent, integrative, collaborative and with the participation of transdisciplinary teams (Embrapa, 2022).

This is why various specific areas within the production chain may be strategically integrated to expand the application of solutions and meets society's demands and the planet's needs. Production systems should not be thought of in isolation, but instead considered with their interdependence among agents from an interconnected and systemic vision (Avery, Kreit & Falcon, 2020).

The topics described here for Agriculture 6.0 already complement each other. One practice creates opportunities for others, enhances efficiency in different areas, or presents solutions in the overall context. Thus, if planned and implemented together with collective actions, utilizing the efforts, infrastructure, and knowledge of various stakeholders along the chain, the gains can be even greater.

Looking at all facets of a challenge allows us to consider the aspects that generate impact in the most different areas. Therefore, the broad visualisation and integrated work between the links in the chain must be increasingly improved so that the convergence of knowledge and the experiences obtained can be collaborative to offer increasingly versatile and effective products and solutions.

5 MANAGERIAL IMPLICATIONS

The proposal of a new technological model that characterises the evolution of agricultural activity focuses on the definition of concepts, systems, technologies/services and study areas so that agribusiness organisations can better understand the transformations that have happened based on the macroenvironment and, consequently, consider these aspects in their planning process. Among the main advantages that the adoption of the concept can bring to the planning process are:

- Optimize the productive efficiency of the systems.
- Reducing production costs;
- Better use of productive resources (and/or by-products).
- Value capture through green markets and environmental preservation.
- Value capture through the carbon market (reduction of emissions).
- Preservation of the soil, ecosystems, and nature.
- Improvement of soil fertility, pest and disease control, plant physiology and, consequently, a better productive environment.
- Search for alternatives for raw material inputs.
- Development of new products, technologies, solutions and services.
- Knowledge and experience from different areas.
- Among others.

Through these aspects, we expect that this content contributes to the decision of organisations, optimising their results, protecting the environment, and contributing to the future of humanity and caring for the people involved directly or indirectly with their activities.

6 CONCLUSION

Remarkably, technological advancement over the years has transformed agriculture and production systems. It has been possible to make production increasingly efficient, productive and sustainable through countless tools, techniques, practices and technologies. Not surprisingly, the trends that have been emerging and should be in evidence in the coming years represent a paradigm shift in the way we see agricultural production today, in line with what future generations want for a better quality of life.

Agriculture 6.0 must be considered with ambition by public and private institutions so that we can continue reinventing ourselves and investing in new technologies that make Brazil emerge as a sustainable world supplier of food, fibres, bioenergy and other agro-products. This new integrating model intends to improve our relationship with the planet and the use of the available resources by the balance between human and environmental well-being.

REFERENCES

Ahmad, L., & Nabi, F. (2021). Agriculture 5.0: Artificial Intelligence, IoT and Machine Learning. CRC Press.

Antar, M., Lyu, D., Nazari, M., Shah, A., Zhou, X., & Smith, D. L. (2021). Biomass for a sustainable bioeconomy: An overview of world biomass production and utilization. Renewable and Sustainable Energy Reviews, 139, 110691.

Avery, M. L., Kreit, B., & Falcon, R. (2020). Foodweb 2020: forces shaping the future of food. Institute for the Future, Palo Alto.

Aznar-Sánchez, J. A., Velasco-Muñoz, J. F., García-Arca, D., & López-Felices, B. (2020). Identification of opportunities for applying the circular economy to intensive agriculture in Almería (South-East Spain). Agronomy, 10(10), 1499.

Barros, M. V., Salvador, R., do Prado, G. F., de Francisco, A. C., & Piekarski, C. M. (2021). Circular economy as a driver to sustainable businesses. Cleaner Environmental Systems, 2, 100006.

BEZERRA, F. D. (2021). Hidrogênio verde: nasce um gigante no setor de energia.

Bulut, C., Nazli, M., Aydin, E., & Haque, A. U. (2021). The effect of environmental concern on conscious green consumption of post-millennials: The moderating role of greenwashing perceptions. Young Consumers, 22(2), 306-319.

Cema. (2017). Digital Farming: what does it really mean? And what is the vision of Europe's farm machinery industry for Digital Farming? European Agricultural Machinery, 2017. Available at: <https://www.cema-agri.org/images/publications/position-papers/CEMA_Digital_Farming_-_Agriculture_4.0__13_02_2017_0.pdf . >.

Chui, M., Evers, M., Manyika, J., Zheng, A., & Nisbet, T. (2023). The bio revolution: Innovations transforming economies, societies, and our lives. In Augmented Education in the Global Age (pp. 48-74). Routledge.

CiBiogás. (2022). Hidrogênio verde: Qual a perspectiva do Biogás para sua chegada ao Brasil? Centro Internacional de Energias Renováveis, 2022a. Available at: <https://cibiogas.org/blog-post/hidrogenio-verde-qual-a-perspectiva-do-biogas-para-sua-chegada-ao-brasil/>.

CiBiogás. (2022). Panorama do Biogás no Brasil 2021b. Centro Internacional de Energias Renováveis, 2022. Available at: <https://cibiogas.org/wp-content/uploads/2022/04/NT-PANORAMA-DO-BIOGAS-NO-BRASIL-2021.pdf>.

Coelho, S. T., Garcilasso, V. P., Ferraz Junior, A. D. N., Santos, M. M., & Joppert, C. L. (2018). Tecnologias de produção e uso de biogás e biometano. IEE Intituto de Energia e Meio Ambiente da Universidade de Sao Paulo: São Paulo, Brazil.

Embrapa. (2021). Crescimento e Intensificação da Produção Agrícola Brasileira. Empresa Brasileira de Pesquisa Agropecuária, 2021b. Available at: <https://www.embrapa.br/en/visao-

de-futuro/intensificacao-tecnologica-e-concentracao-da-producao/sinal-e-tendencia/crescimento-e-intensificacao-da-producao-agricola-brasileira>.

Embrapa. (2021). Embrapa, Mapa e setor produtivo apontam potencial de bioinsumos em reunião do Cosag-Fiesp. Empresa Brasileira de Pesquisa Agropecuária, 2021a. Available at: < https://www.embrapa.br/en/busca-de-noticias/-/noticia/62763679/embrapa-mapa-e-setor-produtivo-apontam-potencial-de-bioinsumos-em-reuniao-do-cosag-fiesp>.

Embrapa. (2022). Visão de Futuro do Agro Brasileiro. Empresa Brasileira de Pesquisa Agropecuária, 2022. Available at: < https://www.embrapa.br/visao-de-futuro>.

EPE. (2022). Fontes de Energia. Empresa de Pesquisa Energética, 2022. Available at: < https://www.epe.gov.br/pt/abcdenergia/fontes-de-energia>.

FAO. (2021). Agricultural Outlook 2021-2030. [Paris], 5 July 2021. DOI: 10.1787/19428846-en.

Giller, K. E., Hijbeek, R., Andersson, J. A., & Sumberg, J. (2021). Regenerative agriculture: an agronomic perspective. Outlook on agriculture, 50(1), 13-25.

Gómez-Godínez, L. J., Martínez-Romero, E., Banuelos, J., & Arteaga-Garibay, R. I. (2021). Tools and challenges to exploit microbial communities in agriculture. Current Research in Microbial Sciences, 2, 100062.

Goold, H. D., Wright, P., & Hailstones, D. (2018). Emerging opportunities for synthetic biology in agriculture. Genes, 9(7), 341.

Gremmen, B. (2022). Regenerative agriculture as a biomimetic technology. Outlook on Agriculture, 51(1), 39-45.

Gusev, E. M. (2020). Evolution of Agricultural Technologies: from “Gray” to “Green”. Arid Ecosystems, 10, 1-9.

Hatanaka, M., Konefal, J., Strube, J., Glenna, L., & Conner, D. (2022). Data-driven sustainability: Metrics, digital technologies, and governance in food and agriculture. Rural Sociology, 87(1), 206-230.

Heading, S., & Zahidi, S. (2023). Global risks report 2023. In World Economic Forum, Genf.

ICC Brasil. (2022). Opportunities for Brazil in Carbon Markets. International Chamber of Commerce. Available in: <https://www.iccbrasil.org/wp-content/uploads/2022/10/RELATORIO_ICCBR_2022_IN_22.10.21.pdf>

Kristoffersen, E., Mikalef, P., Blomsma, F., & Li, J. (2021). The effects of business analytics capability on circular economy implementation, resource orchestration capability, and firm performance. International Journal of Production Economics, 239, 108205.

Lal, R. (2020). Regenerative agriculture for food and climate. Journal of soil and water conservation, 75(5), 123A-124A.

Liu, Y., Ma, X., Shu, L., Hancke, G. P., & Abu-Mahfouz, A. M. (2020). From Industry 4.0 to Agriculture 4.0: Current status, enabling technologies, and research challenges. IEEE

Transactions on Industrial Informatics, 17(6), 4322-4334.

Maffezzoli, F., Ardolino, M., Bacchetti, A., Perona, M., & Renga, F. (2022). Agriculture 4.0: A systematic literature review on the paradigm, technologies and benefits. Futures, 102998.

MAPA. (2021). Plano Setorial para Adaptação à Mudança do Clima e Baixa Emissão de Carbono na Agropecuária com Vistas ao Desenvolvimento Sustentável. Ministério da Agricultura, Pecuária e Abastecimento, 2021. Available in: <https://www.gov.br/agricultura/pt-br/assuntos/sustentabilidade/plano-abc/arquivo-publicacoes-plano-abc/abc-portugues.pdf>.

MAPA. (2023). Projeções do Agronegócio: Brasil 2022/23 a 2032/33: projeções de longo prazo. Ministério da Agricultura, Pecuária e Abastecimento, 2023. Available in: <https://www.gov.br/agricultura/pt-br/assuntos/politica-agricola/todas-publicacoes-de-politica-agricola/projecoes-do-agronegocio>.

Marin, F. R., Pilau, F. G., Spolador, H. F., Otto, R., & Pedreira, C. G. (2016). Intensificação sustentável da agricultura brasileira: cenários para 2050. Revista de Politica agricola, 25(3), 108-124.

Massruhá, S. M. F. S., Leite, M. D. A., Oliveira, S. D. M., Meira, C. A. A., Luchiari Junior, A., & Bolfe, E. L. (2020). Agricultura digital: pesquisa, desenvolvimento e inovação nas cadeias produtivas.

McKinsey. (2022). Mercado voluntário de carbono tem potencial gigantesco no Brasil. McKinsey & Company, 2022. Available at: <https://www.mckinsey.com.br/our-insights/all-insights/mercado-voluntario-de-carbono-tem-potencial-gigantesco-no-brasil>.

Neves, M. F. (2016). Doutor Agro. São Paulo: Editora Gente, 2016.

Neves, M. F. (2021). Etanol de Milho: Cenário Atual e Perspectivas para a Cadeia no Brasil. Ribeirão Preto, 2021.

Paiva, S. D. S. M. D. (2022). Produção de hidrogênio verde ambientalmente sustentável (Master's thesis, Universidade Federal do Rio Grande do Norte).

Saiz-Rubio, V., & Rovira-Más, F. (2020). From smart farming towards agriculture 5.0: A review on crop data management. Agronomy, 10(2), 207.

Schattman, R. E., Rowland, D. L., & Kelemen, S. C. (2023). Sustainable and regenerative agriculture: Tools to address food insecurity and climate change. Journal of Soil and Water Conservation, 78(2), 33A-38A.

Silva, M. B. (2021). Programa Nacional de Bioinsumos: história, situação atual e perspectivas futuras.

Sumberg, J., & Giller, K. E. (2022). What is 'conventional'agriculture?. Global Food Security, 32, 100617.

TNC. (2020). Beyond Sustainable: A Food System to Restore the Planet: Food production is the top threat to nature—a regenerative system can change that. The Nature Conservancy, 2020. Available at: <https://www.nature.org/en-us/what-we-do/our-

insights/perspectives/regenerative-agriculture-food-system-restore-planet/.>.

Tuna, G. (2022). The Impact of Biomass Energy Consumption on CO2 Emission and Ecological Footprint: The Evidence from BRICS Countries. International Journal of Environmental Research, 16(4), 56.

Vargas, D. B., Pinto T. P. & Lima C. Z. (2023). A Transição Verde: Bioeconomia e Converção do Verde em Valor. Observatório de Conhecimento e Inovação em Bioeconomia, Fundação Getúlio Vargas, São Paulo, Brasil, 2023. Available in: <https://agro.fgv.br/observatorio-de-bioeconomia/publicacoes>

Velasco-Muñoz, J. F., Aznar-Sánchez, J. A., López-Felices, B., & Román-Sánchez, I. M. (2022). Circular economy in agriculture. An analysis of the state of research based on the life cycle. Sustainable Production and Consumption.

Venkatesan, M., Dreyfuss-Wells, F., Nair, A., Pedersen, A., & Prasad, V. (2021). Evaluating conscious consumption: A discussion of a survey development process. Sustainability, 13(6), 3339.

Vidal, M. C., Amaral, D. F. S., Nogueira, J. D., Mazzaro, M. A. T., & Lira, V. M. C. (2021). Bioinsumos: a construção de um Programa Nacional pela Sustentabilidade do Agro Brasileiro. Economic Analysis of Law Review, 12(3), 557-574.

Zambon, I., Cecchini, M., Egidi, G., Saporito, M. G., & Colantoni, A. (2019). Revolution 4.0: Industry vs. agriculture in a future development for SMEs. Processes, 7(1), 36.

ZANONI, M. (2004). A questão ambiental e o rural contemporâneo. Desenvolvimento e Meio Ambiente, 10.

Zhai, Z., Martínez, J. F., Beltran, V., & Martínez, N. L. (2020). Decision support systems for agriculture 4.0: Survey and challenges. Computers and Electronics in Agriculture, 170, 105256.