http://doi.org/10.1590/1678-992X-2023-0067

ISSN 1678-992X

Scientia Agricola

Crop Science

Charting new sustainable agricultural innovation pathways in Brazil

Geraldo Bueno Martha Júnior[1]*, Maurício Antonio Lopes[2]

[1]Embrapa Agricultura Digital – Av. André Tosello, 209, Campus da Unicamp, Barão Geraldo – 13083-886 – Campinas, SP – Brasil.

[2]Embrapa Agroenergia – Parque Estação Biológica – 70770-901 – Brasília, DF – Brasil.

*Corresponding author <geraldo.martha@embrapa.br>

Edited by: Jorge Alberto Marques Rezende

Received April 29, 2023
Accepted May 04, 2023

The traditional, low-productive agriculture that prevailed in Brazil until the 1970s was successfully transformed in the decades that followed using a strategy anchored in innovation toward sustained productivity gains (Martha and Alves, 2018). However, it is naive to think that agronomic decisions constituted the core of the decision-making process for transforming the Brazilian agriculture. Policies, economic pressures, and incentives are often the determining factors behind the decision-making process of farmers. Still, there is a need to move further in the sustainability path and solve drawbacks in agricultural production, environment, and social challenges. Furthermore, past achievements do not guarantee future positive outcomes. Thus, when charting new sustainable agricultural innovation pathways in Brazil, it is necessary to recognize, support, and strengthen "science for innovation approaches" to design alternatives to real-world challenges and opportunities.

Agricultural research and development (R&D) have a medium to long maturation time, typically 10-20 years between the conception of a problem to be tackled by the research system and the actual delivery of concrete knowledge and technologies applicable in practice vis-à-vis favorable relative prices. R&D capital lifespan and associated spillovers can last up to 50 years, typically around 25-35 years (Fuglie, 2018). Hence, knowledge and technologies for the decades to come have their roots already in place. Three major branches of technological development will likely be key drivers of Brazilian agriculture: (1) advanced biology, (2) digital transformation, and (3) production systems focusing on sustainable intensification approaches. Here, we present perspectives of the challenges and opportunities on these drivers and their role to strengthen a sustainability path in Brazilian agriculture.

Advanced Biology

Genetics typically accounts for up to 50 % of the contribution to yield gains in agriculture. Such progress is constantly challenged by biotic and abiotic pressures and, increasingly, by evolving intricate economic and legal frameworks. Nevertheless, remarkable scientific advances are taking place in various fields of knowledge. Although conventional breeding approaches will likely remain a pillar of crop improvement strategies, their potential will be augmented by the latest molecular innovations. These range from marker-assisted selection to genomic selection, underpinned by an explosion in available reference pangenomes and paired with advances in high-throughput phenotyping technologies. Modern biotechnology, associated with information technology and advanced instrumentation, is providing a new wave of innovations capable of driving agricultural diversification and value-added strategies, in addition to increased productivity, food safety, and food quality way beyond any past advances.

Genome editing using CRISPR/Cas technologies now offers efficient avenues to create entirely novel alleles or readily introduce rare or recalcitrant natural alleles into elite varieties. We are also gradually learning that factors beyond the coding sequence of genes contribute to trait variation in crops, and progress has been made in understanding the contributions of epigenetic variation and cis-regulatory variation to plant traits. This non-genic variation has excellent potential in breeding, biotechnology applications, and synthetic biology. For instance, synthetic biology resulting from the convergence of digital and biological worlds will pave the way for an impressive range of biopharmaceuticals, bioinputs, and bioproducts creating new synergies of biology, agriculture, and the emerging bioeconomy. Such advanced biology approaches are crucial to expand future resilience, decarbonization, and adaptation strategies to increased biotic and abiotic pressures imposed by climate change on agricultural production systems.

Digital Transformation

Beyond the advances achieved in biology during the past three decades, innovations in the fields of information and communication technology (ICT), remote sensing, advanced instrumentation, automation, and robotics indicate that precision agriculture will soon become a common practice, with potential impact on production, value-added approaches, food diversification, and, more broadly, on bioeconomy chains. These tools and processes will allow more intelligent use of Brazil's vast natural resource basis and, when fully developed, they will ensure higher productivity levels and efficiency gains, as well as improved sustainability in agricultural production systems.

Different aspects of digital technologies applicable to the agricultural sector have become available to farmers over recent decades. Advanced sensors, images (portable devices, drones, and satellites), Internet of Things (IoT), big data, computer vision, and artificial intelligence have the potential to transform agriculture, making it more productive and sustainable. The flow of information and analysis provided by digital solutions can benefit the decision-making process and, potentially, lead to improved planning and selection of better choices at the operational level.

Digital solutions can potentially increase overall efficiency gains, improve resource, and input use, and reduce production costs in agriculture. Furthermore, there is increased demand for digital solutions focusing on monitoring and tracking products and system variables' behavior (soil–plant–animal interfaces). The wide use of these digital solutions aims to increase the volume of data and information on the origin, safety, and quality of food/feed, as well as on agricultural production models and their potential impacts on the environmental and social dimensions.

Despite the potential benefits and growing availability of digital solutions in the market, the adoption of such technologies by farmers has surprisingly not been more widespread, even in countries with a science-based agriculture approach (Lowenberg-DeBoer, 2019). Lack of high-quality access to communication networks and affordable services plays an important role. Furthermore, to date, little evidence demonstrates the widespread economic and environmental benefits of digital technologies, even for well-known solutions, such as precision management technologies (Lowenberg-DeBoer, 2019).

Production systems focusing on sustainable intensification approaches

A bold sustainable intensification strategy – defined as the process of increasing yields while reducing the negative environmental impacts of agricultural production – encompasses a multi-factor approach combining increased yields, cropping intensity, and resource-use efficiency. Over the past decades, Brazil has pursued a sustainable intensification path and looking ahead, output growth will likely be explained mainly by yield gains, as already observed in maize, common beans, beef, rice, and cotton. The contribution of cropland to maize output in Brazil must be carefully analyzed, as 74.5 % of the total maize area (20.9 million hectares) in 2022 was attained from the second-season maize crop following the soybean crop. This approach represents the second pillar of a bold intensification strategy (i.e., increased cropping intensity). Its potential significantly increases within an integrated crop–livestock systems (ICLS) framework. For example, cropping intensity can reach up to three crops a year under rainfed conditions depending on agroecological region.

The productive systems in Brazilian agriculture do not result only from conservation agriculture approaches (e.g., no-till planting and ICLS). They also depend on imported inputs and/or products derived from non-renewable sources. Fertilizers and crop protection inputs, such as herbicides, may represent up to 50 % of production costs and contribute with a similar share to yield gains. A relentless fact is that the agricultural sector will be increasingly pressured to increase the efficiency of fertilizer and pesticide usage in production systems. Therefore, a third pillar of a bold sustainable intensification strategy encompasses approaches to deliver increased resource-use efficiency; therefore, for a given level of input a higher production will be required, or alternatively, for the same output level, a reduction of input usage should be expected. Additionally, such efforts must be coupled with the development and use of viable and effective bioinputs, such as biological nitrogen fixation, to progressively replace inputs based on non-renewable resources in agricultural systems. Technology will thus play a more significant role in the future, both to increase effectiveness in using these inputs and to develop alternatives to replace inputs based on non-renewable resources.

It is worth of noting that over the past decades, Brazil's abundant natural resources have been protected by the enormous land-saving effects (~ 825 million hectares); that is, the land left uncultivated because new technologies have increased the output per unit of area. In other words, without technological development and adoption in Brazilian agricultural and livestock systems, it would have been necessary to cultivate as pasture and cropland, an additional area close to the size of Brazil (851 million hectares) to achieve current levels of crop and beef output in the country. Therefore, despite the adverse effects on agricultural production imposed by climate change, a key future challenge to the broad set of knowledge and technologies encompassed by advanced biology, digital transformation, and novel production systems is to maintain high productivity growth rates cost-effective. Furthermore, under Borlaug's hypothesis, sustained productivity gains are necessary to reduce the pressure to expand cropland. The higher the relative productivity level, the lower is the probability of verifying rebound effects (i.e., Jevons's paradox).

Tropical Agriculture Perspectives in the Bioeconomy Era

Future agriculture should be based on concepts, methods, and multifunctional applicability far beyond the current conventional view. Many essential biological functions adequately studied and known through emerging knowledge and technologies could be gradually incorporated into agricultural value chains. Recent advances already indicate the consolidation of various fronts of advanced biology, represented by genetic engineering, genomics and molecular breeding, metabolic engineering, advanced reproductive technologies, and animal cloning. Such advancements, further fueled by digital transformation, can transform markets and strengthen the possibilities to consolidate Brazil as a dynamic bioeconomy – economy based on biology and biosciences –, developed in synergy with systemic and sustainable modes of agricultural production.

These advances also strengthen Brazilian comparative advantages along food and agriculture value chains. The wide variety of biomass supply (e.g., sugarcane, sweet sorghum, tropical forages, diverse palm species, and co-products) offers opportunities to develop value chains based on high value-added materials and substances targeted at food, feed, flavors, and non-food uses (chemical and biochemical, medical and pharmaceutical, nutritional, and energy). Chemical-bio-catalytic processes lead to the development and use of microbial catalysts that directly convert raw materials into a range of products and chemical intermediates for conversion into new products with high value-added potential.

Thus, strengthening a science-based approach in Brazilian agriculture will not only benefit "traditional" sectors of the economy. From a broader perspective, fostering bioeconomy in Brazil, which already accounts for approximately 20 % of the country's gross domestic product (GDP), will eventually boost the growth of associated capital goods industries, engineering services, and biomass suppliers in food, feed, chemistry, and materials value chains (among others), and create opportunities to expand higher value-added exports. The search for greater efficiency and production linkages should also be pursued in well-known sectoral dimensions, as well as for novel biodiversity uses to deliver innovative products and processes, associated with increased productivity and higher-quality jobs.

Future Challenges

The experience of agricultural transformation in Brazil proves it is possible to have efficient and competitive agriculture in the tropics. Despite the accomplishments, problems between agricultural production and environmental and social issues persist. At an aggregate level, the success of Brazilian agriculture attests that the diffusion of technologies has been a success. However, a large segment of millions of low-income farmers, dedicated to a subsistence activity subsists. The concentration of agricultural output in few farms – 27,300 farms (out of 4.4 million) concentrate 51.2 % of the agricultural sector gross income – indicates the enormous challenge for rural extension and technical assistance in translating the knowledge generated by R&D system into technologies that can be adopted by the vast majority of rural producers (Alves et al., 2012).

In addition, after reaching a minimum of ~ 4,600 km^2 in 2012, deforestation rates in the Amazon Forest averaged ~ 10,600 km^2 per year in 2019-2020. Also, food insecurity was a significant problem in the country during the 1970s and 1980s, but it reached historical minimum levels in 2013 (3.6 % of the population) (Hoffmann, 2021). However, these important achievements in food security were partially or even entirely lost in the past decade. The 2014-2016 recession in the country and the weak economic recovery in the following years reversed that trend and, between 2017-2018, 5 % of a population of 207 million people in Brazil experienced food insecurity (Hoffmann, 2021). The Covid-19 pandemic further aggravated this worrying scenario. Given Brazil's increasing role in contributing to global agricultural output, it is reasonable to assume that tailored policies to assist poorer sectors of the society could somewhat reverse the condition of food insecurity in the country on time. Policies should also consider that Brazil could benefit from actions to advance the multiple dimensions of sustainability (social, economic, environmental) in the following years and decades. Therefore, strengthening a science-based approach in agriculture and, more broadly, in the overall economy will be vital to realizing sustainability goals.

Acknowledgments

We acknowledge the support of the "Projeto Rural Sustentável–Cerrado" (IDB Technical Cooperation #BR-T1409), and two other projects on sustainable intensification approaches (Embrapa and USP/ESALQ, IDEARE #40.22.00.011.00; and Embrapa and Scot Consultoria, IDEARE, #40.22.00.012.00).

References

Alves E, Souza GS, Rocha DP. 2012. Profitability of agriculture. Revista de Política Agrícola 21: 45-63 (in Portuguese, with abstract in English).

Fuglie K. 2018. R&D capital, R&D spillovers, and productivity growth in world agriculture. Applied Economic Perspectives and Policy 40: 421-444. https://doi.org/10.1093/aepp/ppx045

Hoffmann R. 2021. Food insecurity in Brazil after a crisis, its evolution from 2004 to 2017-2018 and comparison with the variation of poverty. Segurança Alimentar e Nutricional 28: e021014 (in Portuguese, with abstract in English) https://doi.org/10.20396/san.v28i00.8663556

Lowenberg-DeBoer J. 2019. The economics of precision agriculture. Chapter 18. In: Stafford, J. ed. Precision agriculture for sustainability. Burleigh Dodds Science Publishing, Sawston, Cambridge, UK.

Martha GB, Alves E. 2018. Brazil's agricultural modernization and Embrapa. In: Amann E, Azzoni CR, Baer W. eds. The Oxford handbook of the Brazilian economy. Oxford University Press, Oxford, UK. https://doi.org/10.1093/oxfordhb/9780190499983.013.15