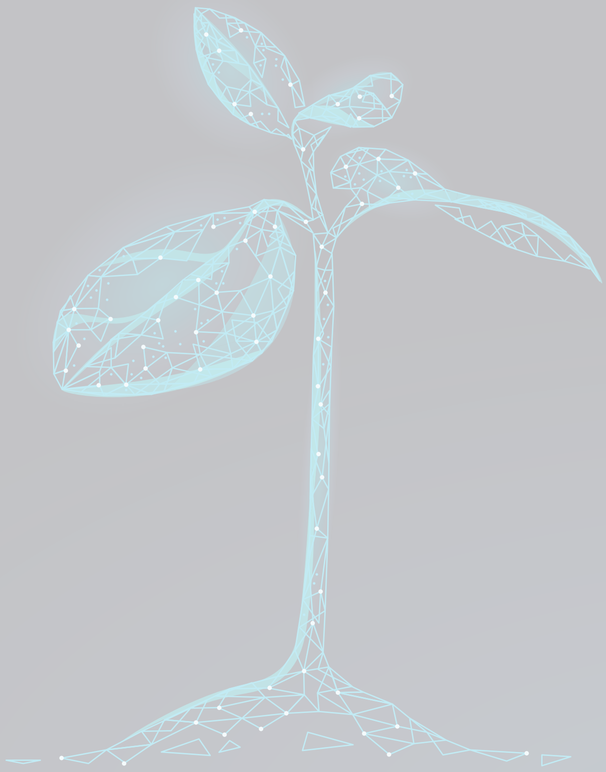
Land-Saving Technologies
2021

Samuel Filipe Pelicano e Telhado
Guy de Capdeville
Technical Editors

Embrapa



Brazilian Agricultural Research Corporation
Ministry of Agriculture, Livestock and Food Supply

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Translated by
Rodolfo Mauro Nunhez

Embrapa
Brasília, DF
2021

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Cover photos
AdobeStock_298389640_planta_Solo
AdobeStock_243600765

Originally published under the title
"Tecnologias Poupa-Terra 2021"
1st edition
ISBN 978-65-86056-09-9

1st edition
Digital publication - PDF (2021)
1st printing (2021): 1,000 copies

Cataloging-in-Publication (CIP) Data
Embrapa, General Division

Land-saving technologies 2021 / Samuel Filipe Pelicano e Telhado, Guy de Capdeville, technical editors ; translated, Rodolfo Mauro Nunhez. — Brasília, DF : Embrapa, 2021.
PDF (160 p.) : il. color

Translation of: Tecnologias poupa-terra 2021, 2021.
ISBN 978-65-87380-43-8

1. Productivity. 2. Agricultural technology. I. Title.

CDD (21. ed.) 630

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Foreword

Projections by the United Nations (UN) for the 2050s clearly indicate that, in the next 30 years, humanity will need to increase its production by 70% to feed the planet. However, Brazilian agribusiness, fundamental in this process, has been suffering criticism that discredits its sustainability. In this context, with the aim of collaborating to demystify the assertion that Brazilian agriculture is not sustainable, we have produced this document showing that Brazilian agriculture is built on scientific bases.

The adoption of a considerable number of technologies on various fronts of the production process has allowed the production of high volumes, with high quality, in a sustainable manner in all aspects, in addition, it has allowed the protection of Brazilian forests both in agricultural properties as well as in native areas. The technological capacity to carry out territorial management, integrated pest and disease management, the use of integrated production systems that extend the life of soils, among other aspects, are the factors that guarantee the success of Brazilian agriculture. Therefore, with the information contained in this document, it is evident that, due to the adoption of technologies developed by Embrapa and partners, agriculture is guaranteed a Land-Saving effect in the most diverse chains of Brazilian agribusiness. The data presented herein are of great value, as they were obtained over decades, which bring robustness to the results disclosed in this document.

We hope that the information made available herein can contribute to demystifying misconceptions and, in a broad and objective way, show that, due to the use of science in support of Brazilian agriculture, the country is and will be sustainable in an environmental, social and economic way, in addition to one of the main actors in world agriculture for the coming decades.

Guy de Capdeville

Executive Director of Research and Development

Contents

Chapter 1

Land-saving strategies and technologies

Their impacts on Brazilian agriculture


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Katia Regina Evaristo de Jesus
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The characteristics of tropical soils are challenging for agriculture. They are naturally acidic and, consequently, have low fertility, which implies constant corrections and replacement of nutrients to ensure high levels of agricultural production. Embrapa has increasingly directed research efforts towards the development of new technologies, practices and processes that enable the increase in productivity with sustainability, considering the use of biological resources for the production of food and other products.

Conservation practices, such as no-tillage planting, management and conservation of soil and water resources can be characterized as land-saving practices, since they increase productivity in a sustainable way. In addition, they have the potential to reverse the negative impacts of actions that employ practices that impoverish the soil, such as continued farming with the use of plows and harrows, the non-use of terraces, among others.

Despite the difficulty of establishing a consensus on the concept of sustainability, sustainable development, in general, has been understood by the characteristic of using resources that meet the needs of the present, without compromising future generations to meet their own needs, as quoted in the Brundtland Report (Comissão Mundial Sobre Meio Ambiente e Desenvolvimento, 1998). This concept integrates the three vectors: environmental, economic and social sustainability.

Concerning agricultural sustainability, the concept could be summarized as the possibility for agricultural systems to maintain long term production, without sensitive depletion of the resources that give rise to them, such as biodiversity, soil fertility and water resources. From a practical point of view, the proper management of available resources can be the starting point for equating sustainability from an environmental and social perspective, in relation to bioenergy generation and food security (Manning et al., 2015; Kline et al., 2017).

This document deals with land-saving technologies, understood as those technologies adopted by the productive sector, whether of low or high cost, that allow sustainable increases in total production in the same area; thanks to their use, the clearing of new areas for agricultural production is avoided. Accordingly, if these technologies were not in use, it would be necessary to dedicate more areas to agriculture for the necessary production of food and energy, which would lead to potentially negative environmental impacts. Thus, land-saving technologies greatly contribute to the environmental, economic and social sustainability of Brazilian agriculture.

Brazil already has a series of sustainable systems and technologies that can be considered land-saving strategies in full adoption. As follows, some of them are highlighted.

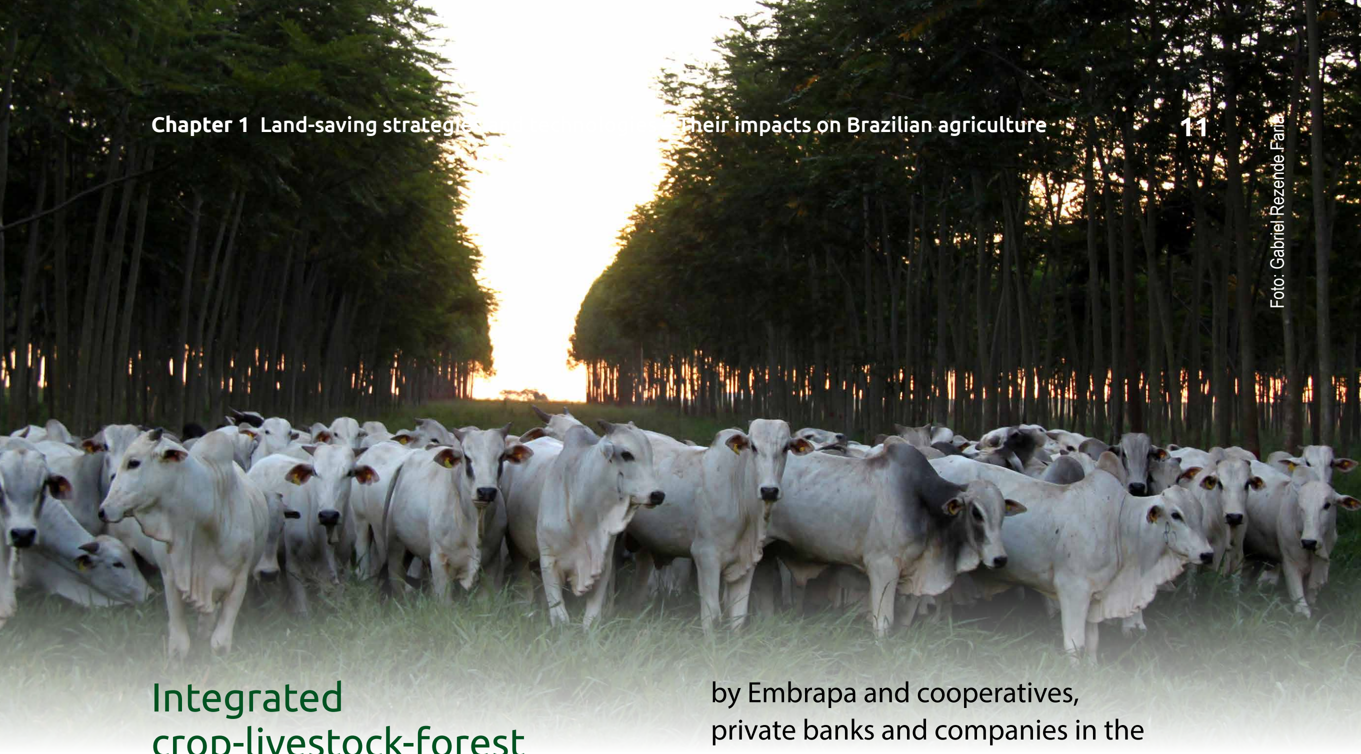

Foto: Gabriel Rezende Faria

Integrated crop-livestock-forest system

The integrated crop-livestock-forest system (ICLF) consists of a strategy that combines livestock, agriculture and forestry in the same area, with mutual benefits for each of them, for the farmer (who diversifies his source of profit over time), and also for the soil, due to the diversification of production, without depleting the resource with a single species or type of production.
It implies benefits and positive impacts both for the environment and for the farmer.

Integrated crop-livestock system is the most used modality, occupying 83% of this area. The demands for timber for sawmill and biomass, combined with the weight gain of animals due to the thermal comfort provided by the shade of trees, has increased the adoption of silvopastoral and agroforestry systems. Embrapa has been carrying out research on integration systems for 30 years. The result is the ICLF Network – formed by Embrapa and cooperatives, private banks and companies in the agribusiness sector. The Network was created to support and encourage the adoption of integrated crop-livestock-forest technologies by farmers, as a unique strategy to expand sustainable production in Brazilian agriculture (Embrapa, 2020).
The 2017 Census of Agriculture indicated an area of 13.86 million hectares of agroforestry systems in Brazil[1]. Mathematical calculations estimate that, in 2020, the area of these systems reached between 15.07 and 17.42 million hectares in the country (Polidoro et al., 2020).

No-Tillage System

The No-Tillage System is a form of conservation management that consists of practices that advocate the maintenance of soil cover, through the maintenance of straw and crop residues. They imply a decrease in soil compaction,

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[1] Available at: https://cidades.ibge.gov.br/brasil/pesquisa/24/0./brasil.

a reduction in erosion and siltation of water resources. This cover protects the soil surface, reduces the evaporation rate, with a consequent increase in soil water storage and maintenance of temperature in the surface layer, favoring the growth of organisms in the soil and, therefore, the increase in organic matter. It results in increased crop productivity (Heckler; Salton, 2002). It is one of the commonly used practices that increase the sustainability of agricultural production in Brazil.

Biological nitrogen fixation

Biological nitrogen fixation (BNF) is performed by bacteria present in the soil or added through the practice of inoculation. BNF was chosen as one of the pillars of the Plano ABC – Agricultura de Baixa Emissão de Carbono (ABC Plan – Low Carbon Agriculture), launched in 2010 by the Ministry of Agriculture, Livestock and Food Supply (MAPA), which was created to encourage the use of sustainable techniques in agriculture, aiming at reducing the emission of greenhouse gases (GHG).

Photo: amenic181 (iStock)

The use of BNF implies a reduction in the need for chemical nitrogen fertilization, with a consequent reduction in the cost of agricultural production and a reduction in negative environmental impacts, since it reduces the contamination of water sources (rivers, lakes and groundwater).

It is, therefore, the process that converts nitrogen from the air into forms that can be used by plants. An important source of nitrogen in Brazilian agriculture, BNF has improved soil properties, resulting in greater productivity, less environmental impact and greater economy. There is a tendency to intensify the use of BNF for crops other than soybeans, namely advancing to grasses, such as maize and others, and for the recovery of degraded areas, reduction of GHG emissions and reduction of contamination risks.

Bacteria allow plants to increase soil phosphorus use

Embrapa has been researching some solution to equate and reduce the dependence of Brazilian agriculture on phosphorus imports. It has recently identified two bacteria capable of solubilizing phosphorus from the soil (Embrapa, 2020), which resulted in the first biological inoculant for phosphorus absorption in Brazil. Results of its application showed an increase in grain yield. Furthermore, its use could, in theory, reduce the potentially negative environmental impacts resulting from its application, such as carbon dioxide (CO_2) emissions into the atmosphere.

Use of bio-inputs to replace non-renewable inputs

Sustainable agriculture in Brazil depends on practices that promote the use of biodiversity and natural biological processes in agricultural production. In this context, the interest and investments in the discovery of new bio-inputs have become increasingly larger. Among the most used bio-inputs, inoculants (which promote the fixation of nitrogen in plants), biological agents for pest control (insects, fungi, viruses and bacteria) stand out, among others, which use biodiversity to provide more balanced and sustainable management tools.

The launch of the Programa Nacional de Bioinsumos (National Bio-inputs Program)[2] in May 2020 (Brasil, 2020) tends to boost the use of biological resources in agriculture and aims to harness the potential of Brazilian biodiversity to reduce farmers' dependence on imported inputs and expand the supply of raw materials for the sector. It is estimated that, with this program, the agricultural area using biological resources will increase by 13%[3].

Photo: Galeanu Mihai (iStock)

Low Carbon Emission Agriculture

The Plano Setorial de Mitigação e de Adaptação às Mudanças Climáticas para a Consolidação de uma Economia de Baixa Emissão de Carbono na Agricultura (Sectoral Plan for Mitigation and Adaptation to Climate Change for the Consolidation of a Low-Carbon Emission Economy in Agriculture) or ABC Plan aims to encourage and monitor the adoption of agricultural practices that reduce emissions and generate resilience without compromising productivity and sector growth.

The following practices tend to reduce GHG emissions and make agricultural production more sustainable and viable in the coming years:

1) Recovery of degraded pastures.

2) Integrated crop-livestock-forest (ICLF) and agroforestry systems.

3) No-Tillage System (NTS).

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[2] Available at: https://www.gov.br/agricultura/pt-br/assuntos/inovacao/bioinsumos.

[3] Available at: https://www.gov.br/agricultura/pt-br/assuntos/noticias/programa-nacional-de-bioinsumos-e-lancado-e-vai-impulsionar-uso-de-recursos-biologicos-na-agropecuaria-brasileira.

4) Biological nitrogen fixation (BNF).
5) Planted forests.
6) Treatment of animal waste.
7) Adaptation to climate change.

PronaSolos

The Programa Nacional de Solos do Brasil (National Program of Brazilian Soils – PronaSolos) (Brasil, 2019) intends to map the national territory and generate detailed data, in order to support public policies, assist territorial management, support precision agriculture and support decisions for lending, among many other applications. It is coordinated by Embrapa in partnership with the MAPA and the Ministry of the Environment. It may allow better soil use, in addition to contributing to greater productivity and, consequently, saving land.

Agricultural Zoning of Climate Risk

The Zoneamento Agrícola de Risco Climático (Agricultural Zoning of Climate Risk[4] – ZARC) is a MAPA public policy implemented by Embrapa. Its purpose is to improve the quality and availability of data and information on the most varied agroclimatic risks in Brazil. It is a fundamental tool to support the farmer in the planning of agricultural activities that consider the climate variability, the soil characteristics and the ecophysiological characteristics of the crop, contributing to the farmer's decisions. Its use is also mandatory for the farmer to access resources from the Programa de Garantia de Atividade Agropecuária (Agricultural Activity Guarantee Program – Proagro) and from the Programa de Subvenção ao Prêmio do Seguro Rural (Rural Insurance Premium Subsidy Program – PSR).

The program undergoes annual reviews and these data are published in ordinances in the Official Federal Gazette.

Precision agriculture

Precision agriculture consists of a set of tools and technologies that allow the farmer to know, in details, technical information of its entire area, which can help increase yields. The technologies used aim to create and employ techniques for handling the spatial and temporal variability of crops, by using future-carrying technologies, such as the internet of things, Big Data, Analytics, robotics, among others, whose potential can drive Brazil to the agriculture of the future.

Today there is the Sistema de Inteligência Territorial Estratégica da Macrologística Agropecuária Brasileira (Brazilian Agricultural Macrologistics Strategic Territorial Intelligence System), which gathers, on a geo-referenced basis, data on agricultural production, storage and harvest routes. With this system, it is possible to extract

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[4] The ZARC Program is governed by Decree 9,841/2019 (Brasil, 2019).

Photo: Smederevac (iStock)

fundamental information for the strategic planning of the government and the productive sector and, consequently, reduce production costs, optimizing planting areas to ensure the rational use of natural resources, especially soil.

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Chapter 2

Development and sustainability in export fruit farming

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Photo: Afrânio Montenegro

The Brazilian fruit farming for the export of fresh fruits and juices, based on science, organization and public policies, has shown an expressive development over the last 3 decades. Technological advances in the production and post-harvest stages resulted in high gains in productivity, quality and socioeconomic and environmental sustainability, with emphasis on the effects of land-saving and saving on the use of natural resources.

Industry data summary

Fruits are grown in virtually every country in the world. According to data from the Food and Agriculture Organization of the United Nations (FAO, 2019), world fruit production reached the volume of 929.6 million tons, obtained from about 80.4 million hectares in 2018.
Brazil is the third largest fruit producer, with 42.4 million tons (4.6% of the total) in 2.5 million hectares, behind China (25.9%) and India (11.9%).
In 2018, it is estimated that its production value generated was 6.5 billion dollars, and that, for each farmed hectare, two people are employed in this agricultural segment, i.e., 5 million jobs in the country are offered in the fruit growing agribusiness, an indicator which emphasizes its socioeconomic importance. Table 1 presents the latest official data related to the employment of direct labor in the production of the main fresh fruits for export.

Table 1. Direct labor employed in 2016 in the production of the main fresh fruits for export in Brazil.

Crop	Quantity(1)
Mango	96,941
Melon	34,749
Grape(2)	261,314
Lime	31,519
Papaya	60,744
Watermelon	165,471
Apple	56,515
Banana	476,806
Total	**1,184,059**

(1) Figures presented by the report based on IBGE data from 2016.
(2) Fresh grape production figures.
Source: Relatório Cenário Hortifruti Brasil (2018).

The Brazilian fruit farming, which is present in all states of the Federation and in the Federal District, can be divided into two categories: temporary fruit and permanent fruit. However, permanent fruits predominate, which, in 2018, represented 92.0% and 87.1% of the harvested area and production, respectively. Tropical/subtropical fruits represented, in 2018, 94.4% of the harvested area and 92.4% of production. In the macro-regions of Brazil, the participation in national production in 2018 was as follows: Southeastern region (51.6%), Northeastern region (25.2%), Southern region (13.7%), Northern region (7.1%) and Midwestern region (2.5%).

Brazilian exports of fresh fruits (including nuts and chestnuts) in 2019 exceeded the amount of 1 billion dollars. Compared to other agribusiness products, fresh fruit exports were in 12th place, representing 1.04% of the Brazilian export basket. In Table 2, it is observed that, in the item distribution, fruits participated with 777.3 million dollars (77%).

Table 2. Brazilian exports of fruits, nuts, chestnuts, preserves and fruit preparations in 2019.

Fruit	Amount (US$)	(%)
Fruits	777,332,539	77
Nuts and chestnuts	162,003,073	16
Preserves and fruit preparations (excl. juices)	70,978,174	7
Total	**1,010,313,786**	**100**

Source: Brasil (2019).

Considering only fruits, in 2019, Brazil exported more than 20 types, with a concentration in eight of them (93.2%) (Table 3). Of these, mangoes, melons, grapes, papayas and watermelons originated mainly from the Northeastern region. Limes come from the Southeastern and Northeastern regions. Apples come from the Southern region, while bananas come from the Southern and Northeastern regions. The participation of the Northeastern region is large, especially in the irrigated perimeters, which have water and a high rate of insolation, favoring the quality of the fruits produced in this region.

As for nuts and chestnuts, the most exported types were cashew and Brazil nuts, which together contributed with US$ 142,280,791.00, corresponding to 87.8% of the item's total. In 2019, the largest share was from cashew nuts, with US$ 121,200,000.00 (74.8%).

Table 3. Brazilian exports of fresh or dried fruits in 2019.

Fresh or dry fruit	Amount (US$)	(%)
Mango	221,801,185	28.5
Melon	160,307,786	20.6
Grape	93,459,500	12.0
Lime and key lime	90,923,279	11.7
Papaya	47,270,134	6.1
Watermelon	43,857,711	5.6
Apple	42,508,683	5.5
Banana	24,559,299	3.2
Others	52,644,962	6.8
Total	**777,332,539**	**100.0**

Source: Brasil (2019).


Photo: Cláudio Bezerra

Regarding the destinations of fruit (including nuts and chestnuts), around 67% were sold for the European Union, followed by the United States, Canada and Argentina, which together

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imported around 20% of the total item. Considering only nuts and chestnuts, the United States (36.8%), the European Union (25.9%) and Canada (10.0%) were the most important destinations.

The production of the main fresh fruits for export can be seen in Table 4. Although banana has the largest harvested area and production, it has the smallest share in exports of this list of fruits.

Brazil is the world's largest producer and exporter of orange juice. In 2019, Brazil produced 17,614,270 t of orange in 608,243 ha harvested, with an average yield of 29 t ha^{-1}. The citrus belt involving regions of the states of São Paulo, Minas Gerais and Paraná, was responsible for 87.7% of the national production, with state participations of 77.5%, 5.6% and 4.6%, respectively. Then the Northeastern region, with a share of 6.7%. In 2018, the orange crop generated a production value of 1.83 billion dollars, ranking seventh in Brazilian agribusiness, after soybeans, sugarcane, maize, coffee, cotton and cassava.

In 2019, Brazil exported 2.1 billion dollars in juices, with a share of 2.18% in the agricultural export basket (9th place). The hegemony of orange juice is expressive, with 1.9 billion dollars, representing 90.5% of the total. As for the other juices exported, the following deserve mention: coconut water, apple, acerola, pineapple, grape

Table 4. Brazilian production of the main fresh fruits for export in 2018.

Crop	Harvested area (ha)	Production (t)	Productivity (t ha^{-1})
Mango	65,646	1,319,296	20.10
Melon	23,324	581,478	24.93
Grape	74,472	1,591,986	21.38
Lime	52,784	1,481,322	28.06
Papaya	27,250	1,060,392	38.91
Watermelon	101,975	2,240,796	21.97
Apple	33,029	1,195,007	36.18
Banana	449,284	6,752,171	15.03

Source: IBGE (2019).

and passion fruit juices. Regarding destination, the European Union is the main buyer (68.60%), followed by the United States (16.7%), Japan (5.3%) and China (3.8%).

Current projections for the demand for fruit in the coming years point to growth in both foreign and domestic markets. The domestic market remains the main destination for Brazilian production and, even with technological improvements in the entire export production chain, this scenario should continue for many years. Table 5 shows the average share of the exported quantity of the main export fruit trees in the total production for the triennium from 2016 to 2018.

Comparisons with other countries production

Brazilian fruit farming stands out for being conducted, in large, in rainfed conditions, with economic viability and with environmental adequacy. However, a significant portion of fresh fruit for export is produced in the Semiarid region, which requires irri-gation. A considerable portion of Brazilian fruit farming is based on small-scale production and family farming, such as the production of cashew nuts in the Semiarid region, under rainfed conditions, with a focus on supplying mini-factories that place their products,

Table 5. Approximate values of the participation of Brazilian exports in the domestic production of the main export fruits, from 2016 to 2018.

Crop	Production (t)	Export (t)	Share of exports (%)
Mango	1,167,845	168,092	14.50
Melon	573,069	218,653	38.27
Grape	1,482,920	38,383	2.61
Lime	1,336,596	95,214	7.16
Papaya	1,138,606	39,901	3.55
Watermelon	2,213,946	69,650	3.15
Apple	1,186,011	52,360	4.36
Banana	6,654,116	57,095	0.86

Source: Comex Stat (2019) and IBGE (2019).


Photo: pixel2013 (Pixabay)

in large, in the domestic market, but increasingly explore the foreign market of fair trade.

In contrast to other countries, the Brazilian fruit farming is a highly diversified activity in its uses and destinations, in addition to a wide internal market at its disposal.
An example is the cashew nut crop, in which the main international competitors focus only on the nuts, while in Brazil a range of products is explored, such as the pseudofruit (peduncle) for pulp, sweets, *cajuína*, the complete cashew for the fresh fruit market and cashew nut liquid (LCC) for the coating, ink, and antioxidant industry.

The Brazilian fruit farming has highly featured the adoption of technological innovations for productivity and sustainability gains, in areas of varietal genetics, planting material production in a protected environment, fertility management and soil and water conservation practices, integrated pest and disease management, among others.

Brazilian fruit farming uses less agrochemical, especially agricultural pesticides. An example thereof is the estimate that, in São Paulo state, around 65% less active ingredient is used per hectare in citrus orchards, due to lower doses and application volumes, compared to orchards in Florida and other Latin American countries, which also has huanglongbing (HLB) as its main phytosanitary threat (Associação Nacional dos Exportadores de Sucos Cítricos, 2019).

Sustainable technologies used in production

Brazilian fruit farming for export does not use genetically modified organisms (GMOs) or antibiotics. All farmed varieties originate from traditional genetic improvement, without artificial manipulation of genes. This is how the matrix of cultivars has been diversified and extended to all main fruit trees.

Crop management

The integrated production system (IP) of bananas, cashews, citrus, papaya, mango, melon, grapes and apples, as a basis for sustainable production and adaptation to the certification programs required by importers, has been consolidated. The IP standards, guided by the Ministry of Agriculture, Livestock and Food Supply (MAPA) (Brasil, 2001), present requirements consistent with or even stricter than those of GLOBALG.A.P., considered a global benchmark for good agricultural practices. IP allows for the traceable production of safe food, free from chemical and biological contaminants, with economic, social and environmental sustainability.

The set of floral induction techniques has been improved, involving the imposition of water stress, intelligent pruning and physiological management, allowing a supply of Brazilian fruits to the markets throughout the year, with a reduction of off-season periods, contributing to socioeconomic sustainability of the activity.

Furthermore, the use of precision farming instruments and strategies has advanced, such as aerial images for diagnosis and specialized management in vineyards.

Mulching management

Good agricultural practices rely on soil conservation practices, especially the use of natural vegetation cover maintained by manual and mechanized tillage, green cover through leguminous and grass species, as well as mulch. These practices aim at the conservation and enrichment of soil microbiota, reduction of water loss through leaching, reduction of soil temperature, longer moisture preservation, among other benefits. Furthermore, mulching contributes to an important carbon immobilization. Pre-emergent herbicides are not allowed in IP. In family farming, and in small orchards, the intercropping of fruits with other smaller crops and shorter cycles is frequent, in order to diversify production and make sustainable use of natural resources.

In addition to plant coverings, other techniques are used to control invasive plants, such as the use of an agro-textile blanket in the melon crop until the pollination stage, resulting in additional benefits such as the absence of insecticide spraying and savings in the use of water.

Photo: Ulrike Leon (Pixabay)

Water and nutrient management

The fruit farming for export in Brazil has improved the management of plant nutrients, including the application of tools such as the Sistema Integrado de Diagnose e Recomendação (Integrated Diagnosis and Recommendation System – DRIS) for interpretation of leaf analysis results, with a marked increase in its efficiency when adjusting doses, shapes and installment of the applications. In addition, the replacement of mineral and synthetic sources by natural and organic fertilizers has been increasing, with beneficial effects on physical and biological aspects of the soil.

The fertilizer recommendation is based on criteria such as reducing production costs and contamination risks, preventing soil salinization and water source contamination. Likewise, the rational use of water has received special attention with a focus on the environmental and economic sustainability of fruit farming.
A significant part of fruit farming is carried out without the help of irrigation. In the case of the citrus belt (São Paulo, southwestern and western regions of Minas Gerais, or *Triangulo Mineiro*) only 30% of the area has this additional water supply.

More efficient irrigation systems, using less water, have been developed and applied in all fruit-producing regions, such as localized irrigation systems and fertigation adopted in mango, watermelon, melon and grape production systems, allowing for greater efficiency in the use of water and rational use of nutrients.

Research by Embrapa and other Brazilian institutions (Santos et al., 2016; Silveira et al., 2020), testing irrigation with a controlled deficit, involving the partial supply of the root system of fruit trees, showed that it is possible to use water depths smaller than those usually recommended. Thus, this water-saving technology has been implemented in several regions.

It is increasingly common to use climatic variables obtained in real time, by agrometeorological stations, to manage irrigation and obtain disease risk indicators.

Integrated pest and disease management

The incidence of pests and diseases is monitored, and control measures are applied only when critical levels of agents are reached. This careful monitoring has given rise to a new role in orchards: a trained employee dedicated to the identification, quantification and control of pests.

The use of pesticides is minimized and, when necessary, it is based on legal active ingredients for each crop based on national and international standards, with special attention to the requirements of importing countries. The applications are carried out with modern equipment and machinery adjusted to adequate spray volumes for each target pest, which leads to important reductions in the amount of pesticide applied.

Classic biological control through the release of natural enemies is widely used in the integrated management of key pests, such as fruit flies, and has been included in the control strategies of an increasing number of pests and diseases through application of entomopathogenic fungi (*Beauveria* and *Metarhizium*) for the control of whitefly, leaf miner, fruit flies, scale insects, coleoptera, mites and leafhoppers; of Trichoderma-based biofungicides for the control of phytophthora and other soil fungi; and bacteria such as Bacillus and Baculovirus in the control of caterpillars and with effects on nematodes. Pest mites have been fought with vegetable oil and the release of predatory mites produced in biofactories. Essential oils such as *Melaleuca alternifolia*, has been used for prevention and control of post-harvest diseases and mold caused by opportunistic fungi.

Cultural control and preventive management practices are emphasized including: cleaning pruning and protecting pruned areas from infection; disinfestation of tools; elimination of infected plants or parts; removal of infected material; prevention of stress and plant wetting; and control of disease vectors.

Applications have been developed to facilitate the identification of pests and diseases of fruit trees, such as the Uzum application for vine farming.

The search for genetic control of the main pests in Brazilian fruit farming is intense, with a series of successes already achieved. The Brazilian Agricultural Research Corporation (Embrapa) conducts genetic improvement programs that have generated new varieties of banana, cashew, citrus, papaya, mango, grape and other fruit trees, with tolerance or resistance to very severe pests and diseases, such as black sigatoka, yellow sigatoka and banana fusariosis, cashew resinosis, canker and citrus gummosis, melon powdery mildew, grape downy mildew, pineapple fusariosis, among others.

Post-harvest management

Boas Práticas de Fabricação e Análise de Perigos e Pontos Críticos de Controle (Good Manufacturing Practices and Hazard Analysis and Critical Control Points) systems are applied in export fruit production, which are important quality control mechanisms for the products offered to the markets.
The use of chemical agents for post-harvest phytosanitary control is restricted, except for a situation that is technically justified and accepted by international certification systems.

In the Brazilian fruit farming, the stress reduction of fruit is ensured through its rational management in harvesting, transport and packaging, with processing carried out in a space with adequate ventilation and light, most often in air-conditioned packing houses and, when the countries of destination require it, the hydrothermal quarantine treatment is carried out to control fruit flies on mango and papaya, and the cold treatment on grapes. Thus, the application of rapid cooling technologies, refrigerated storage and maintenance of the cold chain in transport and distribution of export fruits is common. Disinfection is mandatory, as well as the use of ozone generating equipment in cold rooms and containers, in order to control mold-causing fungi.

As a whole, the sustainable technologies employed in these chains meet at least three of the Sustainable Development Goals (SDGs) proposed by the United Nations (UN) (Nações Unidas, 2012) and agreed upon by several nations: End hunger, achieve food security and improved nutrition and promote sustainable agriculture (SDG 2); Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all (SDG 8); and Ensure sustainable consumption and production patterns (SDG 12).

Logistics aspects that generate sustainability in the production chain

The processes for monitoring the quality and efficiency of the techniques adopted throughout the chain make it possible to assess compliance with the norms that govern commercial relations for importing groups and to identify problems faster. The control in internal processes, specific to the production phase, is local. However, monitoring the shipment of cargo in refrigerated containers to the port or airport requires the use of sensors in order to inform whether the cargo conditions meet the technical recommendations for refrigeration for each type of fruit.
In this stage, the shortest possible land distances are prioritized. However, in the case of maritime transport, which is the predominant one, the operationalization of receiving and dispatching cargo at the ports and the associated costs often interfere in this decision.

Remote monitoring is maintained during the transit abroad and until the cargo is released to the distribution units in each country. Larger companies with greater experience in exporting fresh fruit maintain teams in port cities abroad, in order to analyze the conditions of receipt, the quality of the product, the sampling carried out by importers to analyze compliance with the practiced residue limits, among other aspects associated with certifications.
The volume of Brazilian fruit exports by air is increasing. In the case of papaya, this route represented around 88% of exports between 2011 and 2018, allowing the offer of better quality fruit to consumers.

The main orange processors are located less than 500 km from the export port in Santos, SP. Orange juice is transported in bulk, in tank trucks, to the port by road, which reduces the number of trips required when compared to transport made in 200 L drums (classic form). Maritime transport is carried out on specially developed fruit juice tankers for this purpose, a modality that also reduces the number of trips.

Other relevant information

Organic fruit farming has been fostered by public policies that contribute to its growth at high annual rates. In order to meet this demand, Embrapa has carried out a specific research program and has made organic production systems available for various fruit trees (banana, mango, pineapple, passion fruit). This is another contribution to the supply of healthy fruits, without the use of agrochemicals.

It is evident that there is a growing awareness of the importance of environmental preservation among fruit growers and the consequent observance of the strict rules issued by the Brazilian Forest Code (Brasil, 2012). As an example, it can be highlighted that, in the citrus belt, producers conserve around 180,000 hectares of native vegetation on their properties for around 460,000 ha farmed with oranges. At least 80,000 ha of citrus trees are certified by the Rainforest Alliance, a certification that is also common in the production of mango, grapes and melon.

The search to improve the technological level in fruit farming depends a great deal on the participation of well-prepared human resources. In this context, fruit farming has the support of important organizations for training, technical assistance and rural extension, in the largest fruit production centers, including the Centro de Fruticultura do Serviço Nacional de Aprendizagem Rural (Fruit Farming Center of the National

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Photo: Eduardo Girardi

Service for Rural Apprenticeship – SENAR) in Juazeiro, BA, located in Brazil's main fresh fruits export pole.

Brazil invests a lot in agricultural research, which also applies to fruit farming. Great efforts have been made for technological adjustments that promote increased productivity, with improved fruit quality, in growing systems that are increasingly sustainable from an environmental point of view. An example of this are the strategies adopted for the control or coexistence with HLB, the most severe disease in citrus production worldwide.
One of the strategies has been the sharp increase in planting density, which can make up for the loss of diseased plants. New rootstocks that determine the smaller size of the citrus plant, with greater production of fruits per crown volume and fruits with higher sugar content, developed by Embrapa, are being introduced in the national citrus industry. Many of these new citrus rootstocks have high drought tolerance, representing a valuable aid in adapting the crop to ongoing climate changes.

The production chains of the main exported Brazilian fruits rely on a good integration network of managing institutions, especially associations of exporters, such as Abrafrutas, Brapex for papaya; Frutas do Vale do Rio São Francisco (Valexport), Banana do Norte de Minas Gerais (Abanorte), CitrusBR, Sindicaju, in addition to supporters (federal and state research and technical assistance agencies, Fundecitrus, SENAR), along with MAPA and other relevant ministries. This integration facilitates the joint overcoming of challenges to the opening and maintenance of foreign markets for Brazilian fruits, including phytosanitary barriers. One example is the Systems

Approach program, which allowed Brazilian papaya access to the US market, by integrating pre- and post-harvest practices, taking into account biological, physical and operational factors, to ensure that the fruits are free of fruit flies (*Ceratitis capitata*).

Land-saving effect

Technological evolution in Brazilian fruit farming over the last few decades has resulted in a significant increase in productivity. The comparison of the productivity of the main exported fruits, obtained in 1990 and 2018 (Table 6), shows a general increase of 64% in productivity by volume per hectare, with increases varying between 11% and 137% in the different production chains. This increase in the average productivity represented, in 2018, a land-saving effect of 944,491 ha, which corresponds to around 30% of the area farmed with fruit trees in the country, estimated at around 2.5 million hectares.

Looking specifically at citrus fruits, which occupy the first position in farmed area, production and export, mainly in the form of juice, in the Brazilian fruit farming, there was an increase in productivity of 84.8% for orange and 82.0% for 'Tahiti' lime, with a land-saving effect of 542,936 ha, which corresponds to 84.8% of the area farmed with these fruits in 2018 (Table 6).

The technologies mentioned in the Sustainable Technologies section used in the chains meet the sustainability precepts in their environmental, economic and social segments, resulting in greater efficiency in the use of agricultural areas. Consequently, there are higher productions per unit, reducing the demand for new areas for farming, which contributes to the maintenance of preserved spaces in the different fruit farming regions of the country.

Several examples of the contribution of technologies generated to Brazilian conditions and adopted by fruit production systems, with emphasis on those of importance to the export segment, can be cited. Most of them are supported by the adoption of the integrated production system (Zambolim et al., 2009). Some are specified as follows due to their contribution to better performances per unit of farmed area, overcoming the practice of occupying extensive areas to achieve desirable production.

The various genetic improvement programs developed by Brazilian science and technology institutions have advanced in the availability of cultivars with high productive performance and, in some cases, resistant to biotic or abiotic stresses. Embrapa coordinates programs for the genetic improvement of fruits that lead the production and export rankings in the country, such as banana, citrus, papaya, mango, melon and grapes. Several cultivars and hybrids launched are available on the market, some of which are incorporated into the production chain. An example is the good acceptance and high yields, with relatively lower production

Table 6. Land-saving estimate due to increased productivity in Brazilian fruit production, focusing on the main export fruits.

Fruit	Productivity in 1990 (t ha^{-1})	Productivity in 2018 (t ha^{-1})	Increase in productivity (%)	Production in 2018 (t)	Planted area in 1990 (ha)	Planted area in 2018 (ha)	Saved area in 2018 (ha)
Orange	15.35	28.37	84.8	16,713,000	1,088,795	589,139	499,656
Banana	11.51	15.03	30.5	6,752,000	586,620	449,284	137,336
Watermelon	13.03	21.97	68.6	2,240,796	171,972	101,975	69,997
Mango	10.66	20.10	88.5	1,319,296	123,761	65,646	58,115
Lime	15.42	28.06	82.0	1,481,322	96,064	52,784	43,280
Grape	13.72	21.38	55.8	1,591,986	116,034	74,472	41,562
Apple	18.25	36.18	98.2	1,195,007	65,480	33,029	32,451
Melon	10.52	24.93	137.0	581,478	55,274	23,324	31,950
Tangerine	14.72	19.01	29.1	996,872	67,722	52,450	15,272
Pineapple	33.28	37.04	11.2	2,650,479	79,641	70,553	9,088
Papaya	32.10	38.10	18.7	1,060,392	33,034	27,250	5,784
		Mean	**64.0**			**Total**	**944,491**(1)

(1)The area saved due to the increase in productivity of these 11 fruit trees corresponds to about 38% of the area farmed with fruit trees in Brazil, i.e., about 2.5 million hectares.
Source: IBGE (2019).

cost, of the vine cultivars BRS Vitória and BRS Ísis, in particular the former (Maia et al., 2014). With a stable production area in the main producing and exporting region of fresh grapes in the country, in the last 2 years, the growth of the aforementioned cultivars was based on replacing some of the traditionally adopted ones.

The flowering management technology for production in a period different from the natural stimulus of the plants is an example of productivity gains in fruit production (Albuquerque et al., 2002). The reach and growth of Brazilian mangoes on the foreign market, with the consequent contribution to the generation of foreign exchange for the country, have this technology as one of the enabling elements.

Several management practices and strategies inserted in fruit production meet the challenges of a more efficient production that is integrated into the environment. From this perspective, the integrated management of pests and diseases increasingly incorporates biological control agents in fruit production. Some examples include entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisoplae*, and natural enemies to pests such as the minnow (Leal et al., 2018; Costa-Lima et al., 2019). Bacteria have been important tools and have been multiplied on rural properties, in some chains, such as mango and viticulture.

More directly, an important farming strategy that reduces land use is densification of planting. The concept


Photo: Eduardo Girardi

of intensified farming has densification as one of its bases. The advantages for fruit farming include higher and earlier productions, improved fruit quality, cost reduction and the possibility of mechanizing part of the crop handing (Tripathi et al., 2020). The strategy is enhanced with the use of smaller rootstocks and canopy cultivars, as well as methods of plant height control, either by mechanical practices or by means of plant regulators.
Several national fruit production chains benefit from this type of management, either through a specific practice or through a set of them, showing gains in the efficient use of land, water, nutrients and solar radiation. Cashew and mango farming are important examples.

With regard to soil management, the practices adopted in fruit growing include the use of mulching.
The technique is considered to save water and soil, contributing to sustainable production. According to Kaur and Bons (2017), it brings benefits to the conservation of soil moisture, allows greater efficiency in the use of water, eases soil temperature, suppresses the growth of invasive plants, improves the physical, chemical and biological properties of the soil, in addition to preventing losses by erosion. Thus, the joint effects result in better conditions for growth, production and fruit quality.

Some studies have also quantified the benefits arising from the use of vegetable cocktails in production systems, such as melon and mango. In general, the production of plant matter from the aerial part and the accumulation of nutrients increase with the use of vegetable cocktails, compared to spontaneous vegetation (Giongo et al., 2017). The root system of vegetable cocktails adds greater amounts of vegetable matter and nutrients to the soil, when compared to spontaneous vegetation.
Cycling nutrients and adding nitrogen through legume plants can reduce fertilizer costs. The authors emphasized that conditions conducive to the use of vegetable cocktails, over time, should increase the efficiency of melon crops, positively impacting nutrient cycling and the addition of nitrogen, aside from stimulating soil biota.

In mango farming, the use of green fertilizers as intercropping, regardless of their composition, adds nutrients to the soil, providing increases in productivity. The chemical quality of the soil, in relation to phosphorus, organic matter and nitrogen contents is also improved (Brandão et al., 2017).

In the specific case of citrus production, the following technological innovations that contributed to the great productive advance with a land-saving effect can be highlighted:

1) Development and use of new rootstocks that determined greater precocity, resistance to various diseases and greater fruit production per crown volume and with better juice quality.

2) Adoption of new canopy varieties and more productive clones of traditional canopy varieties, which produce higher quality juice.
3) Higher planting density associated with the use of dwarf or semi-dwarfing rootstocks and/or with smart pruning (Figure 1).
4) Improving integrated pest and disease management with reduced fruit loss.
5) Improving soil management in citrus orchards using green covers.
6) Advances in nutritional management of citrus orchards.
7) Expressive improvement in the quality of citrus seedlings.
8) Migration of plantations to regions that are most favorable to the crop, especially in the midsouthern region of the state of São Paulo.
9) Significant increase in irrigated orchards.

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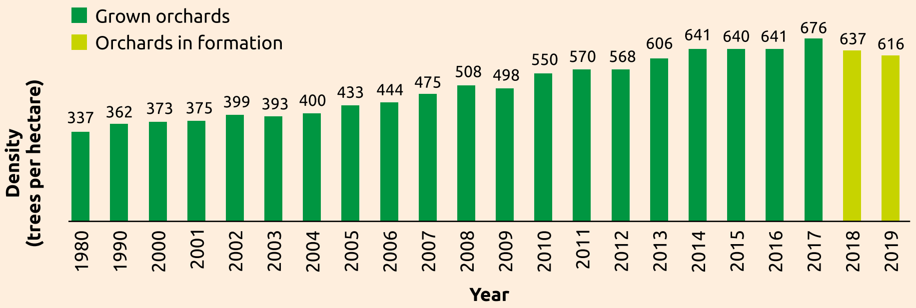

Figure 1. Orange planting density in orchards per planting year in Brazil.

Source: Tree inventory... (2020).

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Chapter 3

The less farmed area, the more technology in export fruit farming

Grape, mango and melon


Photo: Marco Mazucotelli (Pixabay)

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The Northeastern region of Brazil is both a fruit producer and exporter, with its main crops being mango, melon and grapes. This is possible with the use of irrigation and a great amount of technology. With the possibility of producing throughout all months of the year, the center supplies domestic and foreign markets, mainly the European Union and the United States. However, competition with other countries is great and it grows every year. The advantage of Brazilian fruits is that the productivity per hectare has been greatly increased without having to increase the planted areas, thus contributing to saving land.

Contextualization

In 2020, according to Comexstat (2021), Brazil exported around 1.03 billion tons of fruit, a quantity which has been growing every year, as well as export revenues. The main fruits exported by Brazil are mangoes, melons and grapes, which, in 2020, represented 53% of the total volume of fruits exported by the country. The main export destinations are the European Union and the United States; however, exports to Eastern Europe and Asia are growing.

Mangoes, grapes and melons are exported throughout the entire year, as they are produced under irrigation in the Brazilian Semiarid region. However, the highest volumes occur between the months of August to December for mangoes, between September and February for melons and between September and December for grapes.

Brazil, in turn, stands out in the evolution of land-saving strategies for these three crops, as it has a high increase in productivity due to the adoption of different technologies and agricultural practices, mentioned as follows.

Land-saving practices in grape production

The production of fresh grapes for export in the Sub-medium São Francisco Valley is concentrated in seedless grape cultivars. Over the past 15 years, the main technology responsible for major changes in the production system and in the economic profitability of grapes has involved genetics and plant breeding, with the introduction and rapid replacement of cultivars such as Thompson Seedless, Sugraone and Crimson Seedless by new public and private seedless grape cultivars, developed by Embrapa and by foreign private plant breeding companies.

Photo: Paulo Lanzetta

Traditional cultivars would reach average yields of 25 t ha^{-1} with only one annual harvest, associated with negative characteristics such as low bud fertility, susceptibility to diseases and berry cracking during harvesting in the rainy season, increasing the risks of the activity and raising production costs.

Therefore, seedless grape cultivars introduced in the last decade are characterized by high bud fertility that allow for average yields of 50 t ha^{-1}, distributed in two annual harvests. In addition, the new cultivars add other positive characteristics, such as lesser demands on management of the canopy and bunch, less use of growth regulators to increase the size of the berries, and improvement in grape quality, such as a differentiated flavor allowing reaching market niches.

A successful example in the grapevine plant breeding program at Embrapa was the cultivar BRS Vitória (Maia et al., 2014), which, adapting to the Semiarid tropical conditions of the Sub-Medium São Francisco Valley, stood out for its high bud fertility and average yields of 50 t ha^{-1} year^{-1} to 60 t ha^{-1} year^{-1} (Leão; Lima, 2016). The offer of new cultivars such as BRS Vitória consolidated the consumption of seedless grapes in the country and reduced imported volumes in the first half of the year, especially from Chile. From January to June 2019, 6.5 thousand tons of Brazilian seedless grapes were sold at Companhia de Entrepostos e Armazéns Gerais of São Paulo (Warehouses and General Stores Company of São Paulo – CEAGESP), while importing only 1.1 thousand tons (Soprana, 2019).

Thus, over the last decade, despite the significant replacement of imported table grape cultivars by national ones, there was no significant expansion of farmed areas. The volumes produced in the region, according to the Brazilian Institute of Geography and Statistics (IBGE, 2021), went from 232.8 thousand tons in 2004 to 551.3 thousand tons in 2019, i.e., an increase of almost 120%, while the farmed area, which in 2019 was 10,092 ha, increased by 30% in the same period (Figure 1). The increase in

Figure 1. Area and yield of grapes farmed in the Brazilian Semiarid Region from 2004 to 2019.

Source: IBGE (2021).

volumes produced in a smaller farmed area was made possible by the use of productive seedless grape cultivars adapted to the production of two crops per year which, associated with other technologies adopted in the production system, allowed to increase productivity and ensure the quality of the grape. Among these technologies, the reduction in plant spacing stands out, increasing the density of plants per hectare by up to two times.
Plant densification was associated with the formation of a canopy with bi-lateral cordon, a type of formation that became common especially with the cultivar BRS Vitória and with the other cultivars from Embrapa.

Land-saving practices in mango production

Mango farming in the country is of great importance in the economy, mainly due to the generation of jobs and foreign exchange through export incomes.
In the survey carried out to evaluate the performance of mango farming in 15 years (from 2004 to 2018), in the Semiarid region, there was an evolution in the farmed area by 52% and an increase in fruit yield corresponding to 41%, which allowed an increase of 110% in the volume of fruits produced in the period, as can be seen in Figure 2.

When evaluating the total area of mango crops in Brazil, there was a reduction of 3.3% from 2004 to 2019, despite the production having grown 15%, due to the yield of fruits per hectare, which had a 19% increase. In the last 15 years, the increase in mango production is mainly due to mango farming in areas in the Brazilian Northeastern region and northern regions of Minas Gerais, which are characterized by irrigation and the use of pruning techniques to guide the formation of plants. The high planting densities are also highlighted, with an increase of up to 10 times in the number of plants per hectare when compared to the first plantings in the Southeastern region.

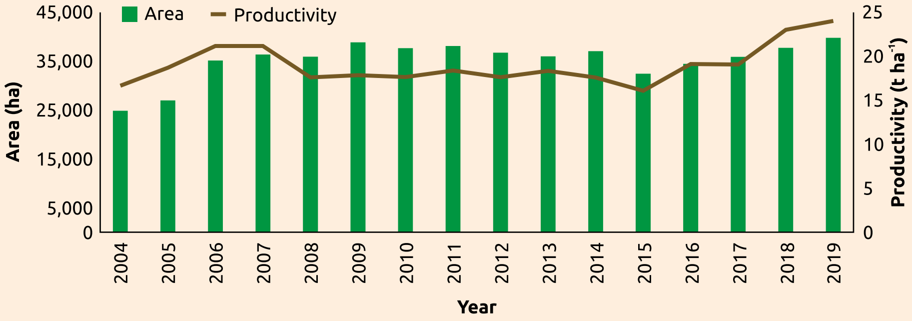

Figure 2. Evolution of harvested area and average yield of mango farmed in the Brazilian Semiarid Region, from 2004 to 2019.

Source: IBGE (2021).

Photo: Shuterbug75 (Pixabay)

Currently, mango crops demonstrate a high technical level: technologies are adopted to manage flowering, aiming production at suitable times for commercialization; fertilization is guided by constant monitoring of soil and plant samples to replenish minerals according to the different demands for each phenological stage of farming; and the phytosanitary management of diseases and pests follows integrated control criteria, with the adoption of registered products and with a lesser environmental impact. In the Brazilian Semiarid region, there are areas with mango trees responsible for more than 90% of production destined for export, and where differentiated technologies are developed and used for the success of mango agribusiness in the country.

Land-saving practices in melon production

In 2019, according to IBGE (2021), 490,175 t of melon fruits were harvested in the Brazilian Semiarid Region. Of this amount, approximately 250 thousand tons were exported, generating revenues of more than 159 million dollars in 2019. In 2020, there was a small drop, and the region exported around 237,000 tons of melon, generating around 147 million dollars in revenue. Rio Grande do Norte state has been the major national producer of melon, accounting for more than 50% of the production and export of this fruit, followed by the states of Ceará, Pernambuco and Bahia. These states stand out because the edaphoclimatic conditions for farming are excellent, with dry climate and high temperatures, ideal for the development of the crop.

Melon is a fruit appreciated worldwide and its demand has been increasing over the last 20 years, thus a great evolution can be observed both in the farmed area and, mainly, in productivity. In the mid-1990s, the area occupied by melon crop was approximately 10 thousand hectares, and productivity was around 14 t ha^{-1} (IBGE, 2021) (Figure 3). In 2019, productivity grew more than the planted area: the area in the Semiarid region exceeded 17 thousand hectares, i.e., a growth of approximately 70%, and productivity jumped to an average of 29 t ha^{-1} (IBGE, 2021), an increase of more than 100%. Land-saving agricultural practices, however, ensured an increase in fruit productivity without expansion of the farmed area, since, if the productivity of the late 1990s was maintained, currently 33,400 hectares would be required to reach the volume produced in 2018, i.e., an extra 19,134 ha. Thus, increased productivity brings a series of benefits, including greater income for the producer and greater

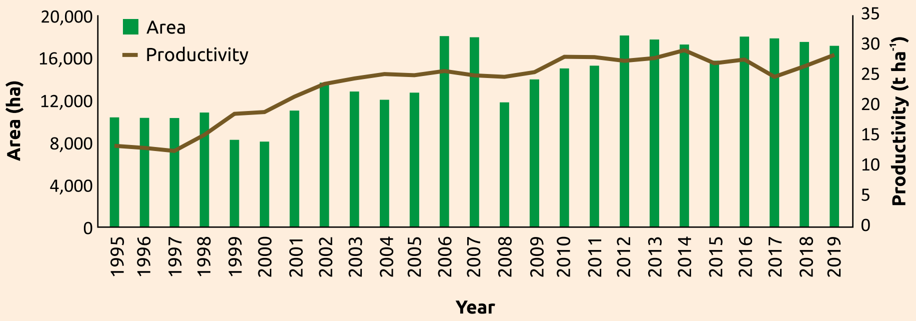

Figure 3. Evolution of harvested area and average yield of melon farmed in the Brazilian Semiarid Region, from 1995 to 2019.

Source: IBGE (2021).

efficiency in the use of water, fertilizers and pesticides, in addition to, consequently, greater efficiency in land use, minimizing the deforestation impacts of new areas.

In general, among the main factors for increasing productivity, the following stand out:

- Introduction of hybrid seeds.
- Adequacy in soil preparation.
- Use of soil analysis for fertilizer recommendation.
- Use of a localized irrigation system (drip) enabling fertigation.
- Application of mulching.
- Use of agro-textile cover over the crop.
- Increased planting density.
- Improvement of integrated pest and disease management.
- Mechanization to implement mulching, agro-textile cover and aid in harvesting.
- Greater qualification of the workforce.
- A large part of these results come from agricultural research in the public and private sectors, which reflect the high increase in crop productivity.

Photo: Andrea Füzesi (Freeimages)

Perspectives

The three crops discussed in this chapter (grape, mango and melon) demonstrate a trend towards continued investment in technologies that allow increased productivity. Likewise, the adoption of management strategies that ensure greater sustainability to crops is highlighted, such as the increased use of biological control of pests and diseases.

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Chapter 4

Sustainability and productivity in cotton agricultural systems

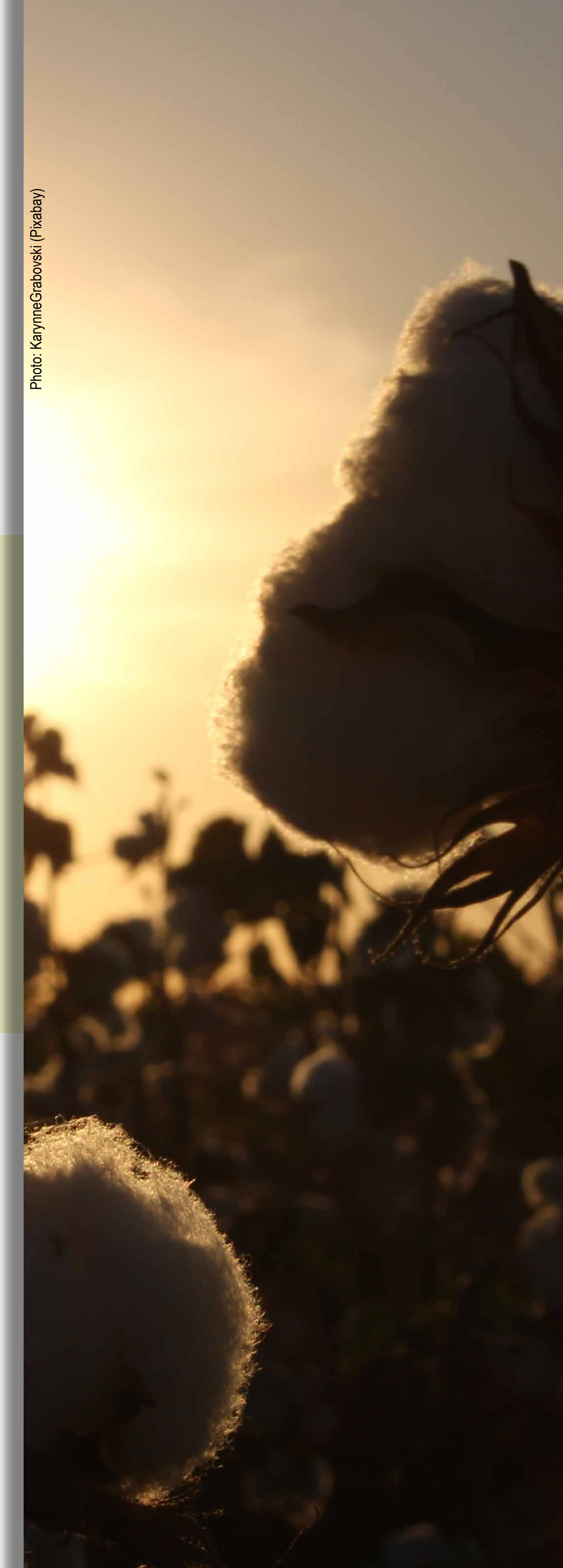

Photo: KarynneGrabovski (Pixabay)

Liv Soares Severino

The development and adoption of appropriate technologies for cotton farming in a tropical environment has resulted in a large increase in productivity. Thus, the cotton production increased with reduction in the planted area. In order to produce the same amount of cotton with the yields of the 1970s, it would be necessary to farm 20 million hectares; currently, to produce the same amount, only 1.5 million hectares are needed, due to the adoption of new technologies and means of production.

Evolution of cotton productivity in Brazil

Between 1976 and 2020, cotton production increased from 0.6 million tons to 2.5 million tons of fiber, while the planted area reduced from 4.1 million hectares to 1.7 million hectares (Figure 1). This growth was due to the impressive increase in productivity: which was only 140 kg ha^{-1} of lint in the 1970s and increased to about 1,730 kg ha^{-1} on the average of the last five cropping seasons, i.e., an increase of 1,100%.

The low productivity of Brazilian agriculture was recurrent, because it employed an agricultural system which had been developed for temperate regions and, therefore, inappropriate for the tropical environment.
As the problems with diseases, pests, and weeds in the country are much more intense, the agricultural system of temperate regions was not sustainable in the Brazilian tropical environment. Thus, the increase in the productivity of Brazilian agriculture only occurred when an appropriate agricultural model was developed for the tropical environment.

In the tropical production system developed in Brazil, the high cotton

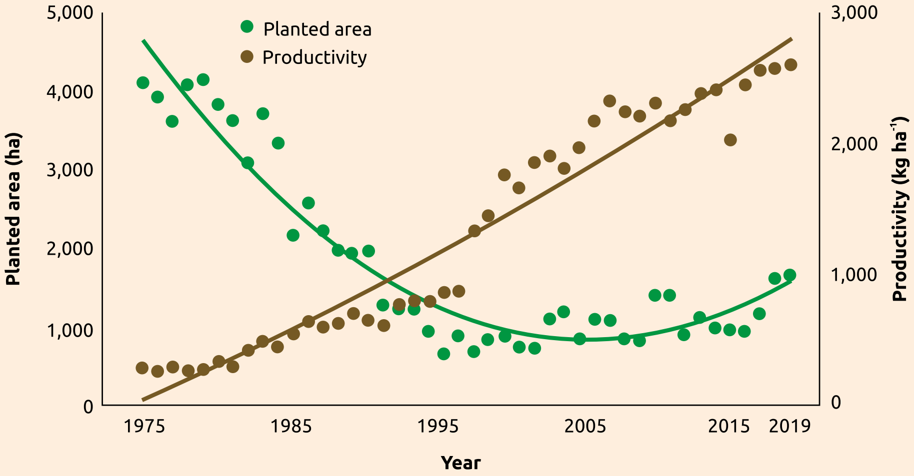

Figure 1. Historical data on planted area and cotton yield in Brazil between 1976 and 2019.

Source: Conab (2021).

yields depend on the adequate combination of several components, among which the following stand out: (i) the genetic characteristics of the cultivars; (ii) the knowledge of tropical soil chemistry and its management; and (iii) the No-Till System with continuous soil cover and the sequence of crops that combine characteristics necessary for the balance of the system. Therefore, in each component of the system, technologies developed over decades of scientific research were employed.

Genetic improvement of cotton cultivars

To assess the productivity and adaptation of the main cotton varieties in the most diverse locations, studies called National Cotton Variety Test are carried out in small experimental plots and adopting the best agricultural practices available. Productivity in experiments, however, is always higher than in commercial crops, but still, they are important to demonstrate the yield potential at that time. Thus, productivity increases occur as producers adopt the varieties that proved to be more productive and the technologies that were recommended.

In the National Cotton Variety Test conducted in 1978 (Freire; Moreira, 1982), while the average productivity in Brazil was 300 kg ha^{-1} of seed cotton, the experimental plots reached yields of 1,100 kg ha^{-1} in the Semiarid region of the states of Ceará and Bahia; and 2,300 kg ha^{-1} in the states of Goiás and Minas Gerais, which today are major cotton producers. The main cotton varieties at the time were IAC 18, SL 7-1, BR-1 and ALLEN 333/57, which are currently considered obsolete and are therefore no longer farmed.

In the year 2017, the average productivity of seed cotton in Brazil was 3,000 kg ha^{-1}, while, in the variety tests, the best varieties reached productivity of 6,300 kg ha^{-1} (Pedrosa et al., 2019). Between 1976 and 2017, genetic improvement made a relevant contribution to agriculture, developing more productive cotton cultivars, which were generated in diversified genetic improvement programs, such as Embrapa, IMAmt, Bayer, Monsanto and TMG. Suassuna et al. (2020), in turn, described the technological progress that was obtained in 30 years of genetic improvement of cotton in Brazil and report yields of some varieties reaching 7,600 kg ha^{-1} under experimental conditions. Another very important factor was that the new cotton varieties were selected not only to increase productivity, but also to resist a list of tropical diseases and pests, to enhance the characteristics necessary for mechanized harvesting, and to improve fiber quality. Without these improvements, it would not have been possible to intensify crops and increase the productivity.

Soil fertility management

In a 1984 report, the use of fertilizers in cotton crops in Brazil reached, on average, only 9% of the amount that

Photo: Fabiano Pierina

should be used, but experimental results showed that cotton productivity could increase up to 70% just by applying fertilizers in the adequate dose with limiting nutrients (Carvalho et al., 1984). By the standards of that time, the increase in productivity was relevant, but in current standard, it would be considered extremely low. The document cites an example of an increase in productivity from 410 kg ha^{-1} to 625 kg ha^{-1} of cotton with the supply of just 75 kg ha^{-1} of phosphorus (Carvalho et al., 1984).

The knowledge on tropical soil fertility management for high-yield cotton crops has been built step by step over decades. The soils of the Cerrado biome, where the expansion of cotton production took place, were extremely poor in phosphorus and very acidic. The studies, however, demonstrated the effects of acidity correction on yield (Amedee; Peech, 1976), improving acidity and phosphorus measurement methods and introducing other characteristics of soil chemistry that needed to be considered. (Quaggio et al., 1985; Montgomery, 1988; Pereira et al., 1989). At the same time, a wide network of laboratories for soil fertility analysis was structured, which enabled the number of soil analyzes carried out in Brazil to increase three fold between 1972 and 1989 (Raij et al., 1994). Fertilizer doses were optimized for the Cerrado growing conditions and for the modern cotton varieties (Borin et al., 2017).

The most up-to-date reports clearly demonstrate that technologies for soil fertility management in the Cerrado were able to overcome the main technological challenges that existed at the beginning of the development of this production system. The highest cotton yields in the state of Mato Grosso are obtained in soils that adopt conservation systems to keep them with a high content of organic matter (Santos et al., 2020). The soils, which initially had extreme acidity, are all within a range close to neutrality (average pH of 6.03 in cotton-grown areas). Thus, productivity peaks are reported, reaching 6,255 kg ha^{-1} of seed cotton in commercial crops in areas with more efficient management, which demonstrates that there is still significant room for increasing productivity (Santos et al., 2020).

No-Tillage System

The previous predominant agricultural system in Brazil was copied from Europe and the United States, with minor adaptations. It was found later that two elements of this system were inadequate for tropical agriculture: the practice of tilling before planting (plowing and harrowing) and planting a species in the same area for several years (monoculture). Tilling is a practice widely adopted in cold regions to destroy weeds and to hasten soil warming, thus favoring seed germination. However, in tropical soils, this practice is deleterious because it create problems, such as reduced organic matter, formation of a compacted layer that prevents root growth, water runoff instead of infiltration, and intense erosion (loss of soil), in addition to increasing the incidence of weeds (Lal, 2015).

In the 1970s, the states of Ceará and Paraná were traditional regions of cotton production in Brazil. In 1976, technical recommendations received by cotton producers in those two states (Sistemas..., 1976a, 1976b), had no comment on the importance of crop rotation or soil organic matter, while there was a strong incentive to the traditional practices of plowing and harrowing the soil. The target for cotton yield in Paraná was 1,750 kg ha^{-1} for producers who had mechanization available and 1,560 kg ha^{-1} for producers who used only animal traction (Sistemas..., 1976b). For Ceará, the target was the productivity of 1,200 kg ha^{-1} with producers of higher technological level and of 600 kg ha^{-1} for low-tech producers (Sistemas..., 1976a). It should be noted that, in both states, the targets set were challenging, as the national average productivity in 1976 was as low as 430 kg ha^{-1} of seed cotton (Conab, 2021). To preserve the soils, only techniques such as planting in contour lines and construction of terraces were applied, without questioning the heavy movement of the soil or favoring the soil cover.

In the agricultural model prevailing in the Semiarid region, there was some diversification due to the intercropping of cotton with food crops (cowpea and maize) and with cattle, also considered an element of diversification (Moreira et al., 1989). This cropping system remained viable for many decades, possibly because it did not include soil tillage, but it had very low yields, as it did not include nutrient input, genetically improved varieties, and mechanization.

When Brazilian agriculture began to expand based on monocultures (little diversity) and intense soil manipulation, on the one hand, productivity was successfully increased, but, on the other hand, the soils degraded rapidly with increased erosion, formation of compacted layer, nutrient reduction, and many other problems (Hernani; Fabricio, 1999), which were also being observed in other regions of intensive agriculture in the world (Lal, 2015). Based on these early findings, the development of a new model of agricultural production began, which, instead of tilling the soil, adopted a continuous mulching with straw, preventing erosion. As scientific evidences of the benefits of conservation practices accumulated, these techniques were increasingly accepted and adopted by farmers (Wiles; Hayward, 1981; Seguy; Bouzinac, 1998; Seguy et al., 1999; Balota et al., 2004; Loss et al., 2012; Souza et al., 2018).

The set of technologies that over time was called No-Tillage System (there are many variations of names) has three main characteristics: the non-tilling of soil, the continuous coverage of the soil with plant residues and the rotation of crops. The scientific challenge of developing the agricultural techniques that allow the effective functioning of this system is still in progress. However, its wide adoption is justified due to its economic and environmental advantages. It was shown that soil organic matter and important nutrient reserves are not depleted with crop intensification when the system includes rotation with species that produce large amounts of straw, like maize and some grasses (Lammel et al., 2017). Soil cover also provides the important service of inhibiting weeds and, consequently, reducing the use of herbicides. (Ferreira et al., 2018).

In a 9-year study, Ferreira et al. (2020) confirmed that the crop rotation including a species that produces large amount of straw not only improved the system's productivity, but it also increased soil organic matter. The increased soil carbon helps to mitigate the greenhouse effect. Currently, cotton production systems in the state of Mato Grosso include rotation in relevant areas with an extensive list of crops: millet (*Pennisetum glaucum*), soybean (*Glycine max*), maize (*Zea mays*), cowpea (*Vigna unguiculata*), rattlepods (*Crotalaria* spp.) and brachiaria (*Brachiaria* spp.) (Santos et al., 2020). Therefore, it was confirmed that cotton yields were much higher in systems that include crop rotation and land cover.

The No-Tillage System had another important benefit for increasing productivity: not tilling prevents evaporation and loss of part of the water accumulated in the soil, in addition to avoiding plowing and harrowing operations, which take several days. Thus, planting can be done immediately after the start of the rains or the previous harvest, as the soil remains continuously under cropping and has better water use efficiency. These details are essential for making feasible planting two crops in the same rainy season. It is noteworthy herein that the productivity gains discussed in this document consider only the isolated numbers of the cotton crop, i.e., if the system's overall productivity increase is considered, much greater gains would be demonstrated.

Sustainability of the cotton production chain in Brazil

Brazil is the world's fourth largest cotton producer and the second largest exporter of this fiber. The estimate for the crop to be harvested in 2021 is 1.4 million hectares, with production of 2.5 million tons of plume and an average yield of 1,743 kg ha^{-1} of plume.

Brazil has the world's highest rainfed cotton productivity. Accordingly, with this high productivity, cotton production in Brazil can expand even more with the exploration of a reduced area, minimizing the environmental impact of the activity. Additionally, Brazilian farmers follow advanced environmental legislation, through which they preserve a large part of their properties as legal reserve and environmental preservation areas, including riparian zones, springs, and mountains.

About 80% of cotton produced in Brazil is certified by the Algodão Brasileiro Responsável (Responsible Brazilian Cotton) and Better Cotton Initiative (BCI), which attest whether production is carried out respecting environmental, social and economic criteria. To achieve this certification, producers need to meet various requirements, such as preserving springs and riparian vegetation, conserving soil and biodiversity, strictly following labor legislation and international conventions for the


Photo: Edna Santos

protection of workers (not using child or slave labor, providing decent working conditions without any discrimination, etc.), and respecting contracts. This certification opens the doors to the Brazilian product to markets that are demanding in preservation criteria to the environment and society. Although cotton production in Brazil represents only 10% of world production, it corresponds to 30% of the world supply of cotton certified by the BCI.

Strategies and land-saving technologies in cotton production in Brazil

Cotton cultivars planted in Brazil have gone through a long and rigorous process of genetic improvement to select varieties that are resistant to a wide list of pests and diseases (bacteria, fungi, viruses, and nematodes). This genetic resistance allows, for example, to reduce the amounts of insecticides to control the aphid insect (which transmits viruses to which some varieties are resistant, such as blue disease and vein mosaic), it does not require the use of products for the control of bacteria that cause angular leaf spot and fungicides for the control of alternaria leaf spot and reduces its use in the management of ramularia disease. Genetic resistance to the root-knot nematode is also a considerable achievement in overcoming phytosanitary problems in cotton farming.

Photo: Fabiano Pierina

Furthermore, cotton production in Brazil is part of a crop rotation system that predominantly includes soybean and maize. There is a significant area in which this system has evolved to also include many other species, such as brachiaria, cattle, millet, sorghum and several other crops in rotation (beans and pulse crops, peanuts, wheat, sesame, chickpeas, castor, crotalaria, etc.). High biodiversity is one of the pillars for the sustainability of tropical agriculture, providing greater efficiency in the use of fertilizers, improved weed management and a reduction in the incidence of pests and diseases. Studies have shown that just the proper of cover crops increased crop productivity by 14%, in addition to providing other major environmental benefits, such as soil protection, better efficiency in the use of rainwater, and reduction in the population of parasite nematode (Ferreira et al., 2020).

In addition to all the benefits mentioned, the production system adopted in Brazil also significantly contributes to combating climate change. For example, the "4 per thousand"[1] initiative was proposed at the *21st United Nations Conference on Climate Change* (*COP21* – Paris, 2015). This proposal consists of increasing, in the planet's farmed soils, the organic carbon content at the rate of 0.4% per year, and, over a few decades, offsetting a large part of the carbon that is released into the atmosphere by other means. Long-term studies conducted by Embrapa provide scientific support to the 4p1000 proposal and demonstrate how its implementation is feasible in Brazil. The study was carried out continuously for 9 years, comparing different forms of soil management and crop rotation, with the inclusion of grasses for straw production, and its effects on cotton yield and soil carbon accumulation, among others important features.

The results proved that the cotton No-Tillage System, integrated with the rotation scheme with maize, soybeans, and *Brachiaria ruziziensis*, increased by 58% the organic carbon content of the Cerrado soil, in the layer up to 5 cm deep, when compared to the cotton monoculture with conventional soil preparation, in which there was no increase in the organic matter content. Considering the depth of 40 cm, which is the suggestion of the 4p1000 proposal, the increase in carbon content in 9 years was 17%, a rate 4 times higher than that recommended in the proposal presented at *COP21*.

It is worth noting that this carbon sequestration is achieved at the same time that productivity increases (158 kg ha^{-1} more fiber every year). In addition, the cotton producer has several other benefits, such as better retention of water and nutrients, in addition to greater stability and resilience to drought spells. This is another example of scientific based contribution that Brazilian agriculture can offer to the great challenge of mitigating global warming, and it supports the Plano Setorial de Mitigação e de Adaptação às Mudanças Climáticas para a Consolidação de uma Economia de Baixa Emissão de Carbono na Agricultura (Sectoral Plan for Mitigation and Adaptation to Climate Change for the Consolidation of a Low Carbon Economy in Agriculture (ABC Plan – Low Carbon Agriculture).

Thus, a variety of more environmentally friendly technologies are being adopted by cotton producers in Brazil, with emphasis on the use of various forms of biological control, such as viruses to control the pest *Helicoverpa armigera*, fungi (*Thricoderma* spp. and *Pochonia* spp.) for controlling nematode and wasps (*Thricograma* spp.) for caterpillar control. Studies are advancing for the biological control of the main cotton pest in Brazil (boll weevil, *Anthonomus grandis*) using insects and fungi.

Perspectives

The cotton crop in Brazil underwent an intense transformation over 4 decades, which resulted in a productivity that jumped from 140 kg ha^{-1} to 1.730 kg ha^{-1}

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[1] Available at: www.4p1000.org.

of lint. This change, in turn, saves, each year, the exploration of 18.5 million hectares of land, considering that the current production of plume would require the farming of 20 million hectares if the productivity of the 1970s were maintained.

There is still room for a significant increase in productivity in the coming years, given the genetic potential that modern cultivars demonstrate in experimental plots and the occasional reports of crops that reach yields far above the national average. Scientific progress in several areas of agronomic knowledge are, therefore, indications that Brazil will be able to maintain the increase in its cotton production without requiring expansion of the farmed area.

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Chapter 5

Coffees of Brazil

Research, sustainability and innovation


Photo: Alexandra (Pixabay)

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The innovative effort of coffee growers, through the adoption of good practices and technologies developed by educational, research and extension institutions, notably those members of the Consórcio Pesquisa Café (Brazilian Consortium for Coffee Research)[1], coordinated by Embrapa Coffee, has contributed to the highly positive performance of Coffees of Brazil, which, among other highlights, has tripled its production volume with a 20% reduction in the respective cultivated area, i.e., approximately 500,000 ha, equivalent to almost twice the area of Luxembourg. This performance reinforced Brazil's leadership in world coffee production, in line with the economic, social and environmental aspects of sustainability.

Coffee sector data and current situation

Brazil has been recognized as the largest producer, exporter and second largest consumer of coffee in the world for several decades. The country has approximately 264 thousand coffee producing establishments, of which 78% are considered coffee family farming (IBGE, 2019). Coffee producing crops are present in the five geographic regions, in 16 states of the Federation, in which there are 1,448 counties that produce coffee, which corresponds to approximately 26% of the Brazilian counties. The Brazilian production, in 2020, corresponded to 2,162 million hectares, an area that includes the arabica and canephora (conilon) species. Of this total, 276 thousand hectares (13%) are under development and 1.885 million hectares (87%) are in production (Acompanhamento da Safra Brasileira [de] Café, 2021). Thus, the coffee production was 63.08 million bags of 60 kg in 2020, with an average productivity of 33.48 bags per hectare, which indicates an increase of 20% in production compared to the previous year, mainly due to the biennial of arabica coffee, a physiological phenomenon of the coffee tree that alternates greater production in one harvest with less in the next. In 2019, the volume of coffee produced in Brazil was 49.31 million bags, with an average productivity of 27.20 bags per hectare (Acompanhamento da Safra Brasileira [de] Café, 2021).

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[1] The Consórcio Brasileiro de Pesquisa e Desenvolvimento do Café (Brazilian Consortium for Research and Development of Coffee – CBP&D/Café), summary name Brazilian Consortium for Coffee Research, was created by means of the Constitution (Brasil, 1997) whose Board of Directors is constituted by the top directors of the following institutions: Brazilian Agricultural Research Corporation (Embrapa); Empresa Agropecuária de Minas Gerais (Agricultural Research Company of Minas Gerais – EPAMIG); Instituto Agronômico de Campinas (Agronomic Institute of Campinas – IAC); Instituto Agronômico do Paraná (Agronomic Institute of Paraná – IAPAR); Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural (Espírito Santo State Research, Technical Assistance, and Rural Extension Institute); Ministry of Agriculture, Livestock and Food Supply (MAPA); Empresa de Pesquisa Agropecuária do Estado do Rio de Janeiro (Agricultural Research Institute of Rio de Janeiro – PESAGRO-Rio); State University of Bahia (UESB); Federal University of Lavras (UFLA); and Federal University of Viçosa (UFV).

As the Brazilian Consortium for Coffee Research, coordinated by Embrapa Coffee, was created a little over 20 years ago, if a comparison of 1997 data with those of the Brazilian coffee industry in 2020 is established, the following evolution of the Brazilian coffee sector from 1997 to 2020 is verified: the productive area was 2.4 million hectares and the production of 18.9 million bags of 60 kg, with a productivity of 8.0 bags ha^{-1}, in 1997, according to the Informe Estatístico do Café (Coffee Statistical Report) (Brasil, 2013). Based on the figures presented, after 23 years, production has tripled with a reduction of more than 20% of the respective area, which corresponds to approximately 500 thousand hectares, on average. Such an area, in comparative terms, is equivalent to almost twice the area of Luxembourg. In addition, it is noteworthy that the Gross Production Value (VBP) of coffee, which was BRL 20.3 billion in 1997, reached BRL 36 billion in 2020 (Embrapa, 2021).

Worldwide, according to the International Coffee Organization (ICO), in 1997, production was 99.9 million 60 kg bags, and Brazil participated with 19% of this market (Organização Internacional do Café, 2021). In 2020, as world production was 171 million bags and Brazil's 63.1 million bags, our share of the world market rose to almost 37%, with a reduction of approximately 20% in the farming area. In 1997, Brazil exported 16.7 million bags and, in 2020, the country had 44.5 million bags exported (Conselho dos Exportadores de Café do Brasil, 2020). Regarding Brazilian domestic consumption in the same period, our country went from 11.5 million bags to 21 million bags, according to the Associação Brasileira da Indústria de Café (Associação Brasileira da Indústria de Café, 2021). Such figures are illustrated in Figure 1.

To implement the National Coffee Research and Development Program (PNP&D/Coffee), established in 1997 by the (former) Ministry of Development, Industry and Foreign Trade (MDIC) and

Figure 1. Evolution of the Brazilian coffee sector in 1997, 2019 and 2020.

Photo: Rafael Rocha

the Ministry of Agriculture, Livestock and Food Supply (MAPA), the Brazilian Consortium for Coffee Research, which has been coordinated by Embrapa Coffee since 1999, was created with the purpose of formulating, proposing, coordinating and guiding strategies and actions for the generation, development and transfer of coffee technology, as well as promoting and supporting research and development and innovation activities to be developed by Embrapa's Decentralized Units, member organizations of the Consórcio Brazilian Consortium for Coffee Research and others of the Sistema Nacional de Pesquisa Agropecuária (National Agricultural Research System – SNPA).

In this context, several technologies developed by the consortium partners have allowed, over the last 2 decades, to increase the production of Coffees of Brazil and promote a reduction of the area occupied by coffee farming.
As Brazil is the fifth largest country in the world, with a total area of 851.57 million hectares, this territorial dimension allows it to explore its area with pastures, farming of crops and forests planted in 255.47 million hectares, the equivalent of 30% of the national territory. And, still, maintain a high level of environmental preservation, since the total area with preserved forests in Brazil is 562.03 million hectares, i.e., 66% of its total territory, according to Miranda (2017). In the specific case of coffee, the area in production corresponds to 1.88 million hectares, a number that represents only 0.73% of the aforementioned area explored in 2019, data from the Cadastro Ambiental Rural (Environmental Rural Register – CAR) analyzed by a study by Embrapa Territorial (Miranda, 2017).

In spite of the fact that the area occupied by coffee crops is not very significant in relation to the area exploited for agricultural activities, Coffees of Brazil significantly contribute to Brazilian agribusiness in both the economic and social aspects. In addition, it is possible to verify that the area occupied by Brazilian coffee farming had a reduction of approximately 17% in the last 2 decades. Even so, in the last 20 years (2001–2020), the volume of coffee produced increased by approximately 200% as a result of increased crop productivity, as shown in the figures presented above (Brasil, 2013; Acompanhamento da Safra Brasileira [de] Café, 2021).

Technologies and their land-saving effect

The increase in production and productivity that enabled the increase in the Brazilian coffee harvest, even with a reduction in the area occupied by crops, can be attributed mainly to technologies developed by teaching, research and extension institutions, notably those that are part of the Brazilian Consortium for Coffee Research, coordinated by Embrapa Coffee, and also for the adoption of these technologies and good agricultural practices by the coffee farmers. In this context, it is worth highlighting some technological innovations, including the sequencing of the coffee genome, which greatly contributed to this trajectory of the Brazilian coffee industry in the last 2 decades.

Coffee genome sequencing

The Projeto Genoma Café (Coffee Genome Project), started in 2002, within the scope of the Brazilian Consortium for Coffee Research, sequenced more than 33,000 genes from the plant.
Thus, most of the sequences obtained were deposited in an international database of biotechnological information, the National Center for Biotechnology Information (NCBI)[2]. This database will make available the sequences of genes that were expressed – Expressed Sequence Tags (EST) – in tissues removed from coffee, in their stages of development or at the time when these tissues responded to biotic or abiotic stresses. Through these EST genes, it is possible to reassemble the RNA molecule, i.e., the DNA copy (cDNA) of the plant that expresses itself at the time of stress. The coffee genome is not only important for research on plant improvement, but also for the development of new crop management technologies, as it is possible to know whether or not the plant has resistance to a certain chemical or biological factor and know the right time to provide fertilizers to optimize the development of coffee trees, as well as other information. As follows, there is a brief report on the main advances in research into the coffee genome developed by the Brazilian Consortium for Coffee Research: more than 33 thousand expression genes identified (cited before); platform for several studies (*Coffea arabica*): quality – aroma, flavor, body, acidity and other desirable characteristics; abiotic stress: drought and high temperature tolerance; biotic stress: rust, miner, nematodes and brown eye spot, among others. In addition, coffee genomics also allowed the development

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[2] Available at: www.ncbi.nlm.nih.gov.

of genetic improvement programs using genotyping at a genomic scale, with the objective of predicting the potential of the plant in the field at the beginning of its development, with the following advantages: cost reduction; time reduction to generate new cultivars/variety; greater efficiency in the development of Brazilian coffee growing, without the need to incorporate new areas to maintain national coffee production.

More productive crops

The permanent development of coffee tree cultivars that have several positive attributes of interest to rural producers and the market, including greater productivity, tolerance and resistance to pests and diseases, and that generate high quality beans and are more adapted to climatic conditions from the different coffee regions of the country, it has been a successful and tireless task of the different genetic improvement programs developed by institutions that have been researching coffee for several decades in Brazil. In this sense, as an example, several superior cultivars developed by institutions of the Brazilian Consortium for Coffee Research can be cited, bearing these positive attributes, such as:
IAC Catuaí SH3, IAC Obatã 4739,
IAC 125 RN, MGS Epamig Amethyst,
MGS Epamig 1194, IAPAR IPR 106,
IAPAR IPR 107, Acauã, Bemtevi, Aranãs,
Asabranca, Siriema AS 1, Arara,
Siriema VC4, IAPAR IPR 103, Araponga
MG, Catiguá MG 1 and MG 2,
Paraíso MG H 419-1, Marilândia ES 8143,
Conilon BRS Ouro Preto,
Jequitibá Incaper 8122,
Incaper 8112 Diamond and
Incaper 8132 Centennial.
These genotypes have high rusticity, and require less use of inputs, notably, pesticides in the conduct of crops and reduction of significant productivity losses due to seasonal weather conditions. Thus, this technological advance has enabled the development of more productive genotypes, which allows for the reduction of crop area for the same production volume.


Photo: Couleur (Pixabay)

Coffee tree farming in a row production system with higher population of plants

Research with different arrangements of plants per hectare, positioning and arrangement of plants in the pit, as well as the number of orthotropic stalks, were fundamental for establishing row planting. This system made it possible to maximize the productive efficiency of the plants, where previously the vast majority of coffee plantation areas used square spacing, at the base of approximately 3 m x 3 m, with planting of 3 to 4 seedlings per hole and less than 800 holes per hectare. In recent decades, it was found that, with the new cultivars available, it is possible to further reduce the distance between plants in the row, to 0.5 m to 0.7 m, with significant increases in productivity, especially in the initial crops. Thus, currently, the production system comprises a variable stand with 6,300 to 8,000 plants per hectare. It is noteworthy that this row planting system reduces the annual production per plant, however, it increases the production per unit area, which contributes to a lesser effect of the biennial production of crops and promotes the stability of Brazilian production.

Adequacy of fertility and nutrition of the coffee tree

Research carried out by the consortium on the dosage of essential nutrients for the development of the coffee tree – nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), boron (B) and copper (Cu) – demonstrated that such products are essential for increasing crop productivity (Ribeiro et. al., 1999; Guerra et al., 2005; Prezotti et al., 2007). With the advances obtained, it is possible to supply the plant's needs according to the phenological state of the crop in the


Photo: Rafael Rocha

field: flowering and fruit expansion, fruit graining and fruit maturation. Soil fertility management is closely related to plant productivity, provided that other production factors are adequate to crop requirements. The coffee tree is characterized by a large export of nutrients from the soil, requiring adequate application of correctives and fertilizers to achieve high yields. In general, they need 16 nutrients for their life cycle, three of which – carbon (C), hydrogen (H) and oxygen (O) – coming from air and water, which make up approximately 95% of the total weight of a plant, and the remaining 13 divided into macronutrients (N, P, K, Ca, Mg and S) and micronutrients (Fe, Mn, Zn, Cu, B, chlorine – Cl and molybdenum – Mo). Since tropical soils, as a rule, are characterized by low fertility, plant nutrition with these nutrients must be balanced to meet its needs, both to optimize the development of the fruits of the pending load, as well as for the development of new branches and buds destined for the next harvest. The most recent results indicate that the nutrition of coffee trees, when performed at the right time and in quantities compatible with the demand of each crop, enhances the full vegetative and reproductive development, increasing, on average, 15% of productivity and allowing the harvest of a higher percentage of fruits with potential for the production of higher quality coffees. This increase in productivity significantly reduces the need to expand areas to meet the current growing demands for commodity and superior coffees.

Coffee tree irrigation management

The adoption of irrigation significantly increases the productivity of coffee plantations, and, in recent decades, this practice has been increasingly widespread. In addition, irrigation makes it possible to produce coffee in areas that were not suitable for this crop. It is estimated that, currently, irrigated coffee production in Brazil represents almost 300 thousand hectares, just over 12% of the coffee plantation, according to Fenicafé (2020). However, the gains with this technique can be nullified due to the inadequate use of water resources by contributing to the occurrence of significant environmental impacts. In this sense, the technologies developed by the consortium resulted in the optimization of the use of water resources with productivity gains of 25%, when compared to farming under dryland conditions, with a reduction in the use of inputs and labor (Guerra et al., 2005). These techniques related to irrigation management enhance the use of smaller areas without losses in national coffee production. In this sense, irrigated areas are responsible for 30% of the national coffee production, thanks to the great advantages of irrigated farming compared to dryland farming.

Controlled water stress

The coffee tree presents a peculiar development, as the vegetative and reproductive growth phases occur simultaneously. In the Cerrado biome region, when the coffee tree is irrigated throughout the year, the plants do not show periods of marked reduction in growth rates, with the appearance and development of new nodes throughout the year. In this situation, three to four blooms can occur, depending on climatic variations, with the consequent uneven maturation at the time of harvest, and it is possible to harvest a maximum of 35% of fruits in the development stage called cherry, suitable for the production of specialty coffees. Controlled water stress is a technique that exposes irrigated coffee to a water deficit in the period of lower water demand of the coffee tree, leading them, after the return of irrigations, to the synchronization of flowering, which occurs in a concentrated manner and with consequent uniformity in the maturation of the coffee beans at the time of harvest. This technique contributes to a 33% reduction in water and energy costs and to an increase in productivity of around 10% and also in quality by obtaining better grain filling (Guerra et al., 2005). These gains contribute to reducing the clearing of new production areas.

Brachiaria as a cover plant

The coffee production system using brachiaria between coffee rows, a technology also developed by the consortium, is a practical solution of simple adoption that requires low investment and significantly contributes to increasing the productivity of coffee tree, preventing soil erosion, adding carbon and nitrogen, recycling nutrients, improving the physical and water quality of this soil and favoring the structural stability of the soil. This technological solution basically consists in cultivate brachiaria (*Brachiaria decumbens*) as a cover plant between the rows of irrigated or dryland coffee tree, in regions with regular water supply and is associated with good practices inherent to this crop, such as its respective cultural management, balanced nutrition and, if applicable, management of the irrigation water with adoption of controlled water stress. The management system between the rows of the coffee tree with brachiaria as a cover plant promotes, in the 0.0 to 0.2 m layer, changes in the physical and


Photo: Ana Labate

water attributes of the soil, resulting in an increase from 18% to 20% in the water readily available from the ground (Rocha, 2014). This increase can be attributed to the conversion of macropores into low retention micropores (Mib) due to the aggregating action of the brachiaria root system which, when associated with regular water supply, provides an increase in the amplitude of the retention curve in the tension range corresponding to water readily available (WRA). Thus, brachiaria as a cover plant, associated with the other technologies mentioned, increases the productivity of the coffee tree and favors the chemical and physical-hydric attributes of the soil, which improves the structure of the soil and its capacity to store water. Furthermore, this production model favors the carbon stock in the superficial layers of the soil, while brachiaria favors the physical attributes of the soil related to the availability of water for the coffee tree. Therefore, coffee tree, due to its longevity, can store carbon for many years, and, when associated with brachiaria, in addition to meeting the main premise of the Kyoto Protocol, related to clean development mechanism (CDM) projects, to reduce the CO_2 of the atmosphere, it can contribute to the sustainable development of the national coffee industry by providing productive and environmental sustainability and, thus, reducing the pressure for area expansion.

Pruning systems

The coffee tree pruning systems have made it possible to combine different technologies that contribute to improving the vigor of the coffee trees so that they reach their maximum productive potential. The main gain of this technological practice is the maintenance of the productive potential of the plants over time, since the production of coffee trees takes place on new branches. Proper management of crops through a combined pruning


Photo: Elias Shariff Falla Mardini (Pixabay)

system can increase productivity by more than 20% and also reduce the need for labor. Coffee tree pruning of the arabica and canephora species comprises the partial elimination of the aerial part of the plant after harvest. This practice generally takes place from August to October and its main objectives are the renewal by induction of productive branches of plants depleted by age, by injuries caused by weather phenomena and/or by the incidence of pests and diseases. Pruning can also efficiently program the management and production of coffee trees in dense cropping systems, reducing the incidence of pests and diseases, facilitating their control. In addition, it allows more light and aeration of coffee trees in crops, improves the architecture of plants by renovating and adjusting the canopy structure, reducing the height and sides of the plants to facilitate cultural handling and harvesting for years to come. Thus, the coffee farmer has an increase in the useful life of coffee production, with vigorous plants reaching higher productivity, without the need to increase cultivated area to maintain their production volume.

Pest and disease management

The incidence of pests and diseases in coffee trees can cause significant damage to coffee crops. In this context, it is worth highlighting some pests of economic importance that attack coffee plants and have been the subject of research within the scope of the Brazilian Consortium for Coffee Research, such as the coffee borer beetle – *Hypothenemus hampei* (*Coleoptera*: *Scolitidae*); leaf miner – *Perileucoptera coffeella* (*Lepidoptera*: *Lyonetiidae*); spider mite – *Oligonychus ilicis* (*Acari*: *Tetranychidae*); cigarrinhas (*Hemiptera*: *Cicadellidae*), among others.

Regarding coffee diseases, research has focused on the following pests and diseases: coffee rust (*Hemileia vastatrix*), cercospora (*Cercospora coffeicola*), phoma spots (*Phoma* spp.), ascochyta spots (*Ascochyta* spp.), target spot (*Pseudomonas syringae garcae*), root-knot nematode (*Meloidogyne*) and coffee ringspot (*Coffee ringspot virus* – CoRSV). To mitigate this problem, the Brazilian Consortium for Coffee Research has intensified the development of technologies for monitoring and controlling pests and diseases in coffee production. In this sense, the integrated management of pests and diseases in the coffee crop contributes to the maintenance of high yields and fruit quality of coffee trees, and reduces production costs and the potential negative impacts of excessive application of agrochemicals. These technologies, when well used, contribute to the expression of the productive potential of crops without the need to clear new production areas.

Protocol for micropropagation

The micropropagation protocol is used in the cloning of arabica coffee trees with superior agronomic characteristics, which allow for increased productivity and improved product quality. In this case, the production of superior hybrids, through the cloning of the coffee tree, reduces the time necessary for the genetic improvement of the coffee tree, allowing the production of large-scale plant seedlings with multiple desirable characteristics. This technology contributes to area reduction due to greater uniformity of superior plants with greater productive potential.

Clonal *Coffea canephora* gardens super-dense with constant arching

This way of conducting clonal gardens aims to reduce the time needed to obtain cuttings for the production of seedlings and enables the production of seedlings of superior genotypes for the renovation of the coffee plant. By the traditional seedling production system, in 36 months, up to 2 million seedlings per hectare can be produced. With the super-dense system technology, developed by the consortium, in the same period, up to 7 million seedlings can be produced per hectare. In addition, other benefits can also be highlighted with the use of this technology: production of a large number of stem cuttings in a reduced area; reduction of time for the production of stem cuttings (anticipating the availability of stem cuttings to coffee growers by more than one year); stabilization of stem cutting production; increased production of stem cuttings in less time; greater uniformity of the stems; and ease of handling and crop handling, which reduces the cost of maintaining the clonal garden. This technology also contributes to area reduction due to greater uniformity of superior plants, which provides greater productive potential.

Perspectives

This demonstrates how the Research, Development and Innovation (RD&I) program, associated with the use of the technologies and good practices mentioned, among others, by coffee farmers, contributed to the advance of the coffee sector in the expansion of production with a reduction in area, which made it possible to guarantee the Coffees of Brazil competitiveness by increasing coffee sector income and environmental preservation.

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Chapter 6

Increased productivity and profitability of maize with technological intensification


Photo: Riteshman (Pixabay)

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In the last 3 decades, maize production in Brazil has quadrupled, a fact that has allowed the country to surpass the 100 million ton mark for the first time. In this process, productivity played a more decisive role in increasing production than the increases in planted area, because the increase in productivity has required less land to increase the supply of maize, resulting in the effect that is conventionally called land-saving.

- In 30 years, production has increased by 359%. This sharp increase in production is due to the increase in average productivity, which went from 1,841 kg ha^{-1} in 1989/1990 to 5,520 kg ha^{-1} in 2019/2020 (200% increase) and a larger planted area, which increased from 12.1 million hectares to 18.5 million hectares (53% increase) in that period.
- To produce the 102.142 million tons of maize harvested in 2019/2020 with the average productivity in effect in 1989/1990, 55.5 million hectares would be needed. Thus, despite the increase in the planted area, 18.5 million hectares, 37 million hectares were saved due to productivity gains.

The adoption and diffusion of new technologies and agricultural practices impacted productivity by overcoming several challenges to make the planting of maize in succession to other crops feasible, with emphasis on the No-Tillage System (NTS), advances in genetics and biotechnology, the construction of soil fertility and improvements in crop handling for the control of weeds, insect pests and diseases. The expansion of maize crop in farming systems, without the need to clear new areas, established Brazil as one of the main world producers of the cereal, and this action was carried out respecting the environment, optimizing the use of natural resources and contributing with the main public policies and conservation goals currently in force in Brazil and in the world, with emphasis on the Sustainable Development Goals (SDGs). In this sense, the following contributions are highlighted to:

- SDG 2 (End hunger, achieve food security and improved nutrition, and promote sustainable agriculture);
- SDG 13 (Take urgent action to combat climate change and its impacts);
- SDG 15 (Protect, restore and promote the sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss).

Contextualization

The millenary trajectory of maize is deeply intertwined with human history. From its origins in Mexico 9,000 years ago to the present day, the cereal earned the status of the world's most important agricultural crop. To justify this statement, it is enough to look at the 2019/2020 agricultural year, when the world production of maize grain totaled 1.11 billion tons (United States,

Photo: Fernando Valicente

2020). The cereal is the only agricultural crop in the world that annually produces more than 1 billion tons, a mark that was only possible to achieve due to its importance in various production chains, from food production to fuel.

The current productive level of maize crop was made possible with the adoption of new technologies and agricultural practices. 60 years ago, in the 1960/1961 season, the world harvested 205 million tons of grain maize. To that end, the cereal was farmed on 105.6 million hectares with an average productivity of 1.942 kg ha^{-1} (FAO, 2020). To obtain the world maize crop in 2019/2020 with the current technological level, in the beginning of the 1960s, more than 570 million hectares would be needed, while under current conditions such production took place in only 192.5 million hectares.

The increase in productivity has required less land to increase the supply of maize to the market, resulting in the effect that is conventionally called land-saving. Among the consequences of the land-saving effect, the release of soil for other activities and less pressure on deforestation to new production areas stand out.

In recent years, some studies have sought to measure the land-saving effect on Brazilian agriculture. Vieira Filho (2016) calculated the effect on livestock at 324.7 million hectares in the period from 1990 to 2015 and on agriculture at 18.6 million hectares, but in the shorter period between 2010 and 2015. In a longer time horizon, Martha Júnior et al. (2012) estimated the land-saving effect on livestock at 525 million hectares between 1950 and 2006. In this context, this document aims to discuss the development of the maize crop in Brazil and the main technological contributions and agricultural practices that allowed this crop to be inserted in the context for the land-saving effect.

Evolution of maize production in Brazil

Historically, maize played an important role in the occupation of Brazilian territory. In colonial Brazil, the cereal was one of the indigenous crops that evolved as a subsistence activity, during the sugar cycle, in the supply of forage to livestock, a fundamental sector in the beginning of the settlement of the interior of the country. (Prado Júnior, 1990). More recently, in the past decades, maize has acquired a new role in the expansion of agricultural frontiers, by being produced in a system in which the cereal is planted in succession to soybeans, supporting the production of the oilseed.

Figure 1 illustrates the evolution of maize production in Brazil during the 20th century and the beginning of the 21st century. It is possible to visualize four phases of maize production in Brazil during this 120-year period.

In the first phase, encompassing the Old Republic (1889–1930) to the beginning of the New State (1937–1946), maize production went through a period of stagnation. Despite the lack of evolution, the crop was already showing some relevance, with grain harvests exceeding 3 million tons, and positioning maize as one of the main agricultural crops in the country.

The second phase is represented by the first major growth cycle of maize crop in Brazil. In the 3 decades between

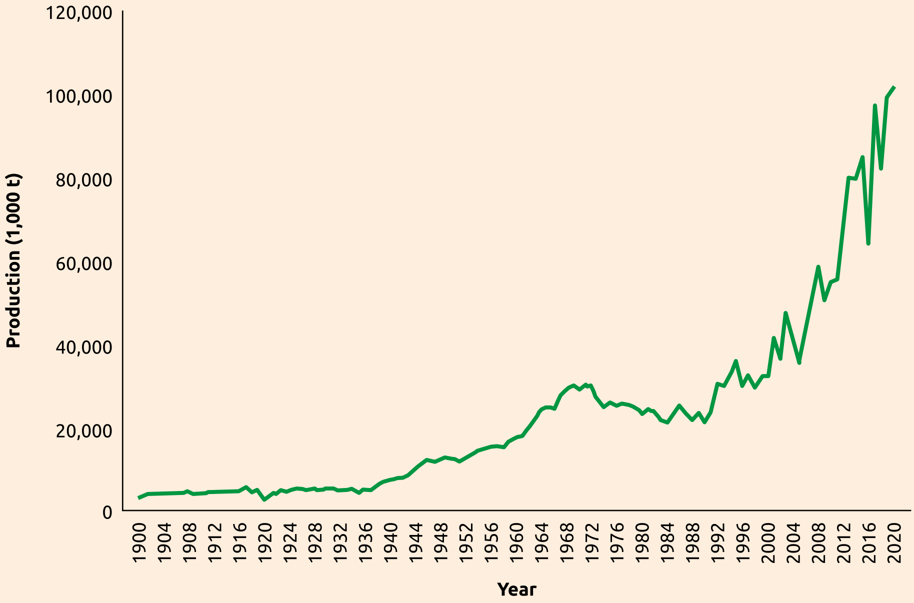

Figure 1. Evolution of maize production in Brazil, from 1900 to 2020.

Source: Conab (2020c) and Ipeadata (2020).

the beginning of the New State and the middle of the Economic Miracle (1969–1973), maize production grew by 500%, from 5 million tons in 1936/1937 to 30.2 million tons in 1970/1971. This growth in Brazilian maize production is explained both by the increase in the planted area (an increase of 172% in the period) and by the increase in productivity (an increase of 121% in the period) resulting from the adoption of new technologies and crop practices.

In this cycle of production growth, it is important to highlight mechanization, seed technology and the so-called Green Revolution. In the period, the number of tractors in Brazilian agricultural establishments increased considerably, from 3,380 units in 1940 to 165,870 units in 1970, an increase of 4,807% (IBGE, 2018). The advance in seed technology can be illustrated by the launch of the first commercial hybrid maize in Brazil, by Agroceres, in 1945. In the following decades, hybrid seed technology would become standard and constituted a fundamental element in the development of the crop in the country. The spread of new agricultural practices and the intensive use of inputs within the scope of the Green Revolution in the 1960s and 1970s considerably impacted not only Brazilian agricultural production, but world production in general.

After the peak of production in the early 1970s, the maize crop in the country went through a period of retraction and would only surpass the mark of 30 million again in the 1991/1992 season. The third phase is represented by the systematic reduction of Brazilian maize production until the mid-1980s. The main reason for this retraction is the rise of soybeans, which now occupy cereal areas in the southern region, then the breadbasket of the country's grain production. The competition with soybeans for planting in the summer, during the rainy and hot season, initially stagnated the planted area and maize productivity, by pushing the cereal to marginal areas, but it engendered the great revolution in cereal production in the last 3 decades, changing the geography and planting time of the crop (Miranda, 2020).

In the late 1980s, maize planted extemporaneously, in February or March, almost always in succession to soybeans, began to gain relevance. This winter maize, or second crop, became popularly known as *safrinha*. In the following decades, the production of second crop maize grew considerably, to the point of relegating summer maize (sown during spring/summer) to a secondary role. In the 2019/2020 season, the first maize crop (summer) accounted for only 25.1% of the record total production of 102.1 million tons (Acompanhamento da Safra Brasileira [de] Grãos, 2020). The second crop maize is the main feature of this second crop growth cycle, as it changed the logic and structure of cereal production in Brazil.

Figure 2 illustrates the trajectory of maize production in the first and second crops over the last 30 years. It is possible to see that summer farming remained

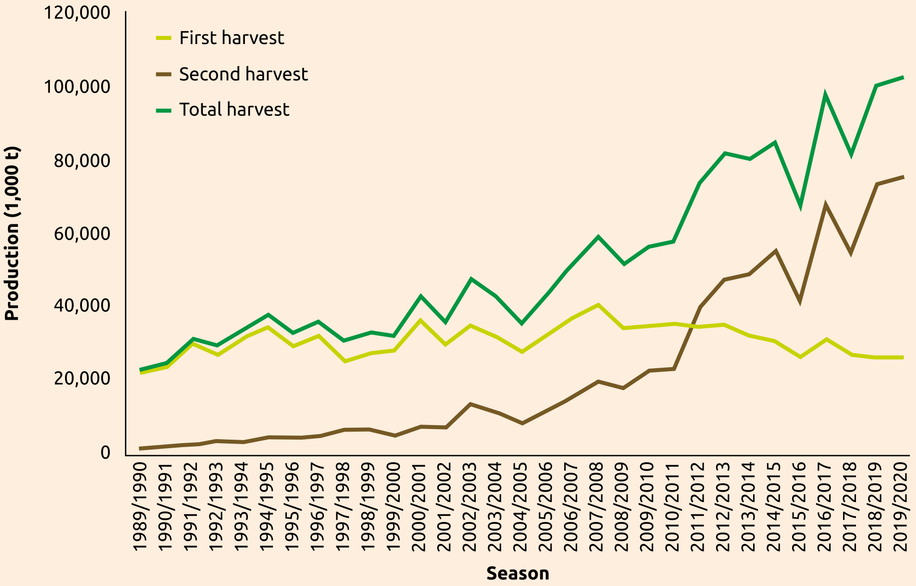

Figure 2. Production evolution in the first and second maize crop in Brazil, 1989/1990 to 2019/2020.

Source: Conab (2020a, 2020b, 2020c).

stagnant, even with a reduction in recent years, and it is the second crop maize that explains the growth of cereal production in the country.

Soybeans not only induced a temporary change in planting of most of the country's maize production, but also changed the geography of the crop. In the wake of the advance of soybeans on the agricultural frontier, mainly in the Midwestern region, maize came next. Figure 3 shows the evolution of maize production in the country by region. There is an evolution in the Midwestern region, becoming the main maize-producing region in the country, with emphasis on the state of Mato Grosso replacing Paraná as a major producer state. In the 2019/2020 season, Mato Grosso accounted for 33.3% of the country's maize production, with 34 million tons harvested, an amount almost three times greater than the harvest in Paraná. In the Midwestern region, maize is predominantly produced in succession to soybeans, ensuring greater profitability for the producer, in addition to providing the sustainability of the No-Tillage System (NTS) in the Cerrado biome.

Technological contributions to the land-saving effect

According to data from the Companhia Nacional de Abastecimento (National Food Supply Company – Conab) (2020a,

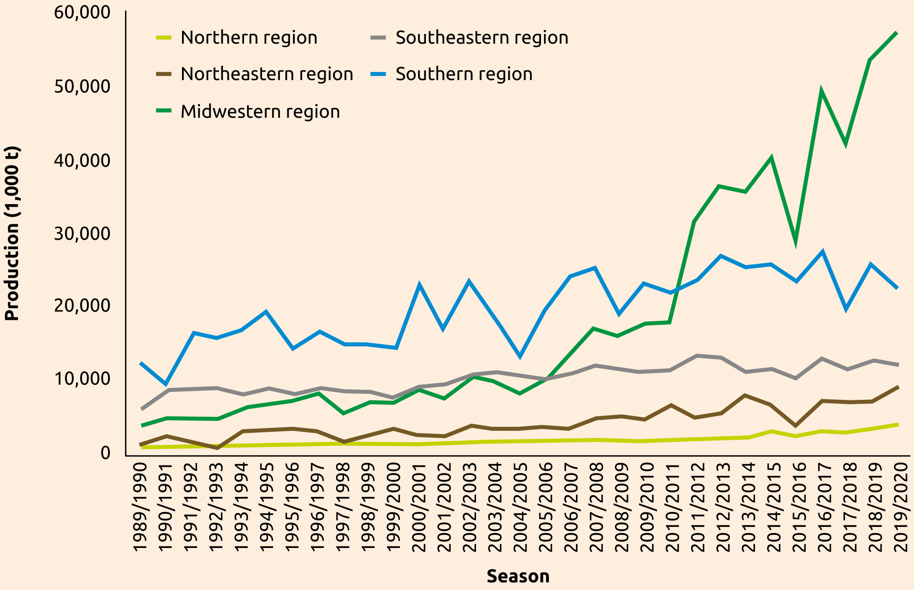

Figure 3. Evolution of Brazilian maize production by region, 1989/1990 to 2019/2020.

Source: Conab (2020a, 2020b, 2020c).

2020b, 2020c), between the 1989/1990 and 2019/2020 seasons, maize production in Brazil increased from 22,258 thousand tons to 102,142 thousand tons (Figure 2). In 30 years, production increased by 359%. This sharp increase in production is due to the increase in average productivity, which went from 1,841 kg ha^{-1} in 1989/1990 to 5,520 kg ha^{-1} in 2019/2020 (200% increase) and a larger planted area, which increased from 12.1 million hectares to 18.5 million hectares (53% increase) in that period.

To produce the 102.142 million tons of maize harvested in 2019/2020 with the average productivity in effect in 1989/1990, 55.5 million hectares would be needed. As a result of the increase in productivity, it was possible to produce the amount of the 2019/2020 season in 18.5 million hectares, in succession to soybeans. Thus, despite the increase in the planted area, 37 million hectares were saved due to the gains in productivity.

The increase in the area planted with maize did not mean a need for more land, as the second maize crop in rotation with soybeans boosted the intensification of land use. In 1989/1990, the total area planted with maize grain, 12.1 million hectares, was predominantly under summer farming, 95.7% of the total, with many areas underutilized in the winter, after harvest. In the

Photo: Gustavo Porpino de Araújo

2019/2020 season, maize grain in the summer was farmed in just 4.2 million hectares, with the remaining 14.3 million hectares planted in the second or even in the third harvest in succession to other crops. It is evident that, analyzing historical data, the significant growth of maize production in Brazil was evidenced by the technology available to Brazilian producers, increasing the supply of soybean and maize in the same farmed area. In the last 30 years, grain maize production has almost quintupled, and summer maize area has decreased by two-thirds. In this sense, a land-saving effect occurred through the intensification of land use through the feasibility of soybean-maize farming.

This particularity of the maize crop in being able to be farmed at different times of the year in an economically viable way, resulting in multiple crops, it provides an additional dynamism to the crop in terms of the land-saving effect, as it is not explained only by productivity. Over the last few decades, the adoption and diffusion of new technologies and agricultural practices impacted productivity and made it possible to plant maize in succession to other crops, especially soybean, resulting in the land-saving effect, among which the NTS, genetics and biotechnology, the construction of soil fertility and advances in crop handling for the control of weeds, insect pests and diseases.

No-Tillage System

Among the conservation practices that reconcile productivity and conservation of natural resources, the NTS is adopted in approximately 35 million hectares in Brazil (Federação Brasileira de Plantio Direto e Irrigação, 2020). For tropical conditions, this farming system is based on three agricultural principles: no soil disturbance with agricultural implements, ground cover with vegetable residues (straw) for as long as possible, and crop rotation (Blanco-Canqui; Ruis, 2018). Among the agricultural crops that guarantee the versatility of the NTSin different Brazilian biomes, maize is considered strategic for the sustainability of this technique, as it presents important characteristics such as broad adaptability and productive stability even in autumnal crops, as it allows multiple purposes for crops in rotation or succession to soybeans and, also, it is intercropped with other plant species as in the cropping modalities in integrated crop-livestock-forest systems (ICLFs) (Borghi et al., 2013).

The choice of maize to compose a crop rotation system for the NTS is due to many reasons. Belonging to the Poaceae family, maize has a large straw production capacity, above 13 t ha^{-1} (Resende et al., 2016) and with a high carbon/nitrogen ratio, which gives it a slow decomposition on the soil surface. In many producing regions, this straw remains on the soil until the soybean is grown in the following agricultural year, reducing the presence of weeds and reducing soil loss due to the erosive process caused by rain. In addition, maize roots, which occupy a large volume deep in the soil, form natural channels that allow for greater water infiltration and, through their decomposition, increase the action of beneficial microorganisms, providing improvements in physical, chemical and biological conditions of soil and, consequently, progressively increasing crop productivity over the time of NTS adoption (Borghi et al., 2019).

In Central Brazil, maize sown after soybean (known as second crop maize) guarantees the advance of the NTS in many Brazilian states.
The soybean/ second crop maize crop was established thanks to technological advances in both crops, allowing for a reduction in the soybean cycle and, subsequently, ensuring the planting of maize in NTS. Kappes (2013) reported that soybean breeding over the last decades, seeking precocity combined with the indeterminate growth habit in soybean, also caused anticipation in the soybean sowing season by almost 50 days, when compared to the period of 1985/1990. In 30 years, thanks to technological advances for these two crops, the second crop maize farmed area went from 256,000 hectares in the 1989/1990 season to 13.73 million hectares in the 2019/2020 season. With adaptive research in producing regions, trained technicians and the producer employing the best agricultural practices in order to enhance production and optimize the available natural resources,

the average productivity of second crop maize, considering this same historical series, went from 966 kg ha^{-1} in 1989/1990 to 5,454 kg ha^{-1} in 2019/2020.

According to Contini et al. (2019), maize farming in rotation, succession and intercropping, thanks to the wide plasticity and adaptability of the cultivars available on the market, has yields in the second crop equal to or higher than the summer growing season. Thanks to this breadth of possibilities, second crop maize represents the economic viability for the adoption of the NTS by Brazilian producers (Miranda et al., 2011). Planted area data that make up the crop monitoring report prepared by Conab, in August 2020, show that 37% of the soybean farmed area in Brazil received maize as a result. The Midwestern region adopts this crop system in greater proportion (54%), and the states of Mato Grosso and Mato Grosso do Sul are the largest producers of this soybean/maize sequence in NTS, representing, respectively, 54% and 61% of the 2019/2020 season soybean area. Other states, such as São Paulo, Rondônia and Tocantins, which have increased the area farmed with soybeans in recent years, also adopt maize in the sequence, consolidating the significant increase in the NTS area in Brazil by the soybean/maize binomial. In these states, this sequential farming already represents 48%, 58% and 23% of the area farmed with soybean, respectively (Table 1).

Table 2 shows an analysis of the farmed area and productivity of the two crops in the last decade, also based on data from Conab (2020c, 2020d). In this period, while the area farmed with soybean grew by 63% (increase of 11.5 million hectares in the farmed area), second crop maize increased in a greater

Table 1. Second crop soybean and maize farmed area in the main producing states of these crops in Brazil, in the 2019/2020 season.

Region/state	Farmed area (thousand hectares)		
	Soybean (a)	Second crop maize (b)	b/a
Brazil	**36,949.0**	**13,735.8**	**37%**
Midwestern Region	**16,640.1**	**8,926.2**	**54%**
Mato Grosso	10,004.1	5,414.4	54%
Mato Grosso do Sul	3,016.4	1,840.0	61%
Goiás	3,545.1	1,633.7	46%
Federal District	74.5	38.1	51%
Southern Region	**12,085.1**	**2,259.2**	**19%**
Paraná	5,502.7	2,259.2	41%
Southeastern Region	**2,757.1**	**973.6**	**35%**
Minas Gerais	1,647.3	442.8	27%
São Paulo	1,109.8	530.8	48%
Northern Region	**2,110.0**	**531.2**	**25%**
Rondônia	348.4	186.0	53%
Tocantins	1,078.0	240.7	22%
Pará	607.4	101.1	17%

Source: Conab (2020c, 2020d).

Table 2. Evolution of area (million hectares), productivity (kg ha^{-1}) and growth percentage of soybean crop and maize second crop, 2009 /2010 to 2019/2020 seasons.

	Area	Productivity (kg ha^{-1})
Soybean		
2009/2010	18.1	2,671
2019/2020	29.5	3,466
Growth (%)	63	30
Mayze		
2009/2010	4.9	4,164
2019/2020	13.7	5,454
Growth (%)	280	30

Source: Data obtained from the historical series available by Conab, (Acompanhamento da Safra Brasileira [de] Grãos, 2020).

proportion of farmed area (280%), however, only by 8.8 million hectares. Crop productivity, considering this same series of data, grew homogeneously, 30% for both. Thus, it is possible to infer that the farmed area with second crop maize expanded in greater proportion last decade, however, this increase was due to the advance in soybean farming. Although the expansion of the oilseed is in greater evolution due to the possibility of farming under degraded pasture areas in the Cerrado biome, the farming of maize in autumn/winter, sown immediately (or simultaneously) with the soybean harvest, consolidated the productive intensification in the Cerrado with these crops, resulting in an increase in the volume of maize produced by 54.3 million tons, thanks to the soybean/maize rotation in SPD.

As a public policy, the NTS is part of the Plano Setorial de Mitigação e de Adaptação às Mudanças Climáticas para a Consolidação de uma Economia de Baixa Emissão de Carbono na Agricultura (Sectoral Plan for Mitigation and Adaptation to Climate Change for the Consolidation of a Low Carbon Economy in Agriculture – Plan ABC). Since 2011, the ABC Plan encourages producers to adopt sustainable production technologies that have been proven to be efficient in mitigating greenhouse gases. According to the information note prepared in 2018 by the Coordenação de Agropecuária Conservacionista, Florestas Plantadas e Mudanças Climáticas (Coordination of Conservation Agriculture, Planted Forests and Climate Change) on the adoption and mitigation of greenhouse gases by the ABC Plan technologies, it was shown that, between 2010 and 2016, the NTS expanded by 9.97 million hectares, corresponding to 125% of the target proposed by the government to increase the area farmed with this technology in the country by 2020 (8 million hectares). In this same period, according to Conab's historical series, the second crop maize area increased 5.29 million hectares, following the advance of soybeans. Thus, considering the data in the report and the expanded area of second crop maize farming in the period 2010 to 2016, it can be observed that, with the SPD technology through the farming of maize sown after soybean, this rotation system can have contributed to 66% of the target proposed in the national policy of the ABC Plan.

Considering the annual mitigation potential proposed in the ABC Plan

Photo: Gisele Rosso

for the NTS (1.83 Mg CO_2 equivalent ha^{-1} year^{-1}) (Plano..., 2012) and the period from 2010 to 2016, the NTS was responsible for the mitigation of 18.25 million Mg CO_2 equivalent, and, from this total, the farming of second crop maize contributed to 9.6 million Mg CO_2 equivalent[1].

Maize is the second grain-producing crop in Brazil, second only to soybeans. Thus, with the possibility of second crop farming, the soybean/ second crop maize rotation increased the economic yield of the producer in the same area, making this system sustainable. According to Borghi et al. (2019), factors such as those described above make maize indispensable for the sustainable intensification of Brazilian agriculture, enabling an increase in food supply in areas already occupied by agriculture, with increasingly intensive, resilient production systems and optimizing the use of natural resources available (Resende et al., 2019).

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[1] The calculation made in this document refers only to an estimate, with the objective of showing a contribution for the farming of second crop maize, having as a reference the mitigation value proposed by the Ministry of Agriculture, Livestock and Food Supply (MAPA) for the NTS. For greater assertiveness on the contribution of second crop maize, new studies should be conducted to know the actual mitigation value, considering exclusively the soybean/maize system.

Contributions of the technological intensification of maize farming in the areas of genetics and biotechnology for the land-saving effect

To meet the global demand for food and biofuels in the coming decades, it will be necessary to double the yields of crops such as maize, rice, wheat and soybeans. (Ronald, 2011; Alexandratos; Bruinsma, 2012; FAO, 2012). Maize productivity increases in the world occur at a rate of 1.6% per year, and it is necessary that this rate rise to 2.4% to guarantee the global demands forecast for 2050 (Ray et al., 2013).

Studies to assess the productivity gains obtained for the maize crop in the USA in the last 50 years indicated that 48% of these gains were due to genetic improvement and 52% to change in crop management practices (Duvick, 2005). These studies also showed that the gain in productivity in maize crop was mainly due to the improvement in characteristics that promote greater efficiency in grain production and greater resistance to biotic and abiotic stresses.

The genetic progress obtained by maize improvement in Brazil was studied by Von Pinho et al. (2016). It was found that between 1976 and 2015 the grain yield of the crop increased 331% (from 1,632 kg ha^{-1} to 5,396 kg ha^{-1}) and that this increase in productivity was the main reason for the national production to go from 19.3 million tons to 84.3 million tons in this period. One of the main factors to explain this increase in maize productivity in Brazil was the availability of new, more productive hybrids together with the adjustments made to the production system. Oliveira (2013) compiled productivity data from properties considered to be of medium to high investment, observing an increase in productivity of 120 bags ha^{-1} in 1976 to 185 bags ha^{-1} in 2009, with an average gain of 2 bags ha^{-1} year^{-1}. These changes resulted from cultivar replacement strategies in Brazil, from double hybrids in the 1970s to triple hybrids in the 1980s and 1990s. Since 2000, simple and transgenic hybrids that allow the maximum expression of heterosis predominate in the country. This last characteristic is defined as the increase in production or vigor in the progenies from the interbreeding between contrasting individuals, making it possible to obtain more productive cultivars, resistant to stress and easier to manage (Shull, 1908; Hallauer; Carena, 2009; Tang et al., 2010).

It is worth highlighting, in Brazil, the great impact of changes in maize improvement programs resulting from the advent of second-crop maize production, known as *safrinha* maize, deployed mainly in the same area in succession to soybean crops. Figueiredo et al. (2015) report the effects of genotype x environment interaction when the same hybrids were used in first crop and off-season conditions. Genetic improvement aimed at selecting maize cultivars for the second crop has focused on characteristics such as higher precocity (shorter cycle allows the crop to take advantage of the end of the rainy season after soybean harvest), dry down (rapid drying that allows anticipating harvesting), stay green (the plant remains green and photosynthesizing while the grains dry), greater tolerance to lodging and breakage (to allow mechanical harvesting) and greater resistance to disease. This has allowed the new hybrids for second crop farming to show greater adaptability (produce well in different regions) and production stability (less variations in production at different times and years).

Among the technologies that allowed greater intensification of maize production in the country is the adoption of transgenics. The use of crops with resistance to glyphosate made it possible to control weeds in large areas with an increase in the window of application of the herbicide in the crop, allowing the area to be desiccated before planting. The second major technological intervention of biotechnology in maize was the control of insects, which, associated with integrated pest management, was a fundamental factor in obtaining better results.

With the release of the first transgenic events for the farming of maize in the country as of 2007, the dynamics in the production chain changed to such an extent that, in the 2018/2019 season, around 90% of the maize farmed area corresponded to genetically modified cultivars (Isaaa, 2018). Of 166 maize cultivars available for sale in the 2018/2019 season, 123 were carriers of transgenic events (Pereira Filho; Borghi, 2020). These data attest to the acceptance of this technology by the farmer and the response of the seed market to this demand.

A 2018 study, conducted by Agroconsult and the Conselho de Informações sobre Biotecnologia (Biotechnology Information Council – CIB), entitled *Economic and socio-environmental*

Photo: Fernando Vallcente

impacts of insect resistance technology in Brazil: historical analysis, perspectives and future challenges (Impactos..., 2018), analyzed the economic impact of the adoption of transgenics in soybean, maize and cotton crops in the period from 2010 to 2018. The additional revenue from the three crops added together was US$ 5.9 billion. This result comes from an additional production with the use of genetically modified organism (GMO) technology to control insects in the order of 55.4 million tons of grain, of which 4.55 million tons of soybeans, 50.8 million of tons of maize and 46 thousand tons of cotton. In relation to costs, an additional investment of US$ 0.85 billion was evidenced, with spending on transgenic seeds, surpassing the savings with the reduction of pesticides. This resulted in US$ 5.1 billion in aggregate profits and US$ 4.1 billion in relation to maize. The study also highlights that a significant part of the benefits attributed to insect resistance technology can be analyzed from an environmental point of view. According to estimates, there was a withdrawal of 2.6 million tons of CO_2 atmosphere equivalent, with a reduction of 112 thousand tons of insecticide, 144 million liters of fuel and a reduction in the planted area in the period from 2013 to 2018. Furthermore, the study by Agroconsult/CIB (Impactos..., 2018) is a forecast until 2027/2028, measuring aggregate benefits in the order of 107.1 million tons, US$ 16.6 billion in sales, total cost reduction by US$ 3.7 billion and US$ 20.3 billion in total profits. This disaggregated information for the maize crop was estimated at 86.1 million tons, US$ 9.5 billion in sales, total cost reduction of US$ 752 million and US$ 20.3 billion in total profits. In terms of technologies that bring the future to the advancement of maize genetics in Brazil, the importance of technologies such as:

- Elite germplasm introgression, mainly of temperate origin in combination with tropical material, aiming to increase the effects of heterosis for genetic gains in the crop.
- Large-scale application of phenotyping, such as the use of drones and hyperspectral cameras to assess crop development.
- Application of strategies to more reliably relate phenotype to genotype, which includes the use of techniques for genotyping and/or genome sequencing.
- Search for strategies that make it possible to reduce the time to develop new cultivars, such as increasing cycles/year of evaluation/advancement of cultivars, assisted selection to accelerate character introgression, the use of double-haploid technology, and rescue embryo among other strategies.
- Use of transgenics and/or genome editing to obtain cultivars with characteristics of interest in a more targeted and assertive way.

Soil fertility and its relationship to sustainable maize crop intensification

Most of the arable surface of Brazil is composed of very weathered, oxidic soils and naturally devoid of abundant reserves of nutrients. Therefore, the chemical improvement of fertility constitutes the initial stage and the indispensable basis for the successful intensification of land use. As a result of research started more than 50 years ago, practices involving the use of corrective materials and fertilizers so that acidic and nutritionally deficient soils can become able to support profitable agricultural production are well established and disseminated.

Where the land is cultivated in a technified way, with annual crops for longer, the residual effect of successive fertilization promotes the gradual increase of nutrient reserves in the system. As a result of this process, there is a tendency to increase areas in which the current availability of nutrients is already above critical levels, characterizing soils with built fertility. For crops in this condition, opportunities for more rational use of fertilizers emerge, without loss of yield, maintaining soil fertility and increasing producer profitability (Resende et al., 2019).

The consolidation of the use of conservation management systems, such as the NTS with species diversification, is another factor that has favored the improvement of fertility. This advantage stems from the prevention of losses due to erosion and nutrient unavailability, but, above all, from the conservation of soil organic matter, increasing the productive potential of crops and, consequently, the land-saving effect. Data from Embrapa Cerrados proved that the consolidated NTS enables maize productivity 6% higher than in the conventional soil tillage system (Sousa et al., 2016). According to the field history of management and fertilization, it is possible to produce satisfactorily with adjustments to reduce the maintenance doses, as in the case of phosphate fertilizers, which recovery utilization rates can approach 100% in the NTS (Sousa et al., 2016), a condition of efficiency much higher than those reported so far.

Historically, the performance of Brazilian agriculture has been closely and directly related to the use of fertilizers. Over the last 5 decades, the production and productivity of the main crops have been increasing, in parallel with the growth in fertilizer consumption. Between 2000 and 2015, the use of fertilizers grew 87%, converging on a 150% increase in grain production in the same period (Embrapa, 2018).
By constituting one of the factors that promote the increase in yield per area, fertilization has contributed to reducing the pressure to clear new land for agricultural use in the country (Lopes; Guilherme, 2007). Therefore, as the expansion of the farmed area has been occurring in a much smaller proportion than the increase in the demand for fertilizers, it is clear that this investment

in the maintenance of soil fertility is one of the agricultural technologies that contribute to the land-saving effect in the Brazil.

Maize occupies the second position in farmed area, after soybeans, and the consumption of nutrients in these two crops corresponds to more than 50% of the fertilizers applied to Brazilian soils today. In the wake of technological advances, statistics on the use of fertilizers in Brazil confirm that maize crop has evolved in terms of productive efficiency, in which the growing yield gains per area occurred in parallel with a lower dependence on nutrient supply.

Comparing the deliveries of NPK fertilizers in 2008 with the average for the years 2013 to 2016, there is an increase of about 27% in the maize consumption in the period (Figure 4). The corresponding amount applied per hectare of maize had a smaller increase, of 17%, while the NPK consumption ratio for each ton of grain produced showed a decrease of 13% in the same period (Figure 5). Therefore, these indicators reinforce the perception that the growing maize production throughout the historical series has materialized, much more due to the gains in productive efficiency resulting from the development and application of farming technologies, than due to the increase in the planted area.

Crop handling

Weed management

Weeds should be considered the main problem for world agriculture, as Land Care of New Zealand estimates the global losses caused by weeds in the order of 95 billion dollars per year, and 78% of this amount is lost in developing countries (FAO, 2009). Estimated

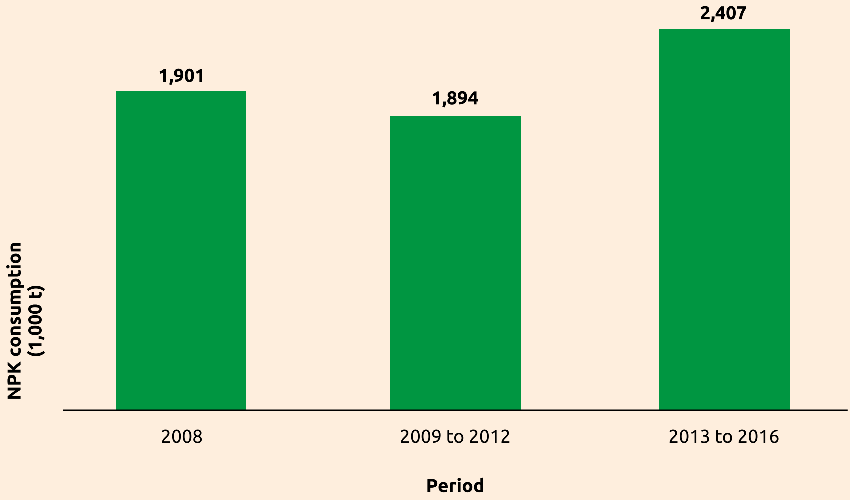

Figure 4. Evolution of global consumption of NPK fertilizers in maize crop in Brazil, from 2008 to 2016.

Source: Adapted from Cunha et al. (2010, 2014, 2018).

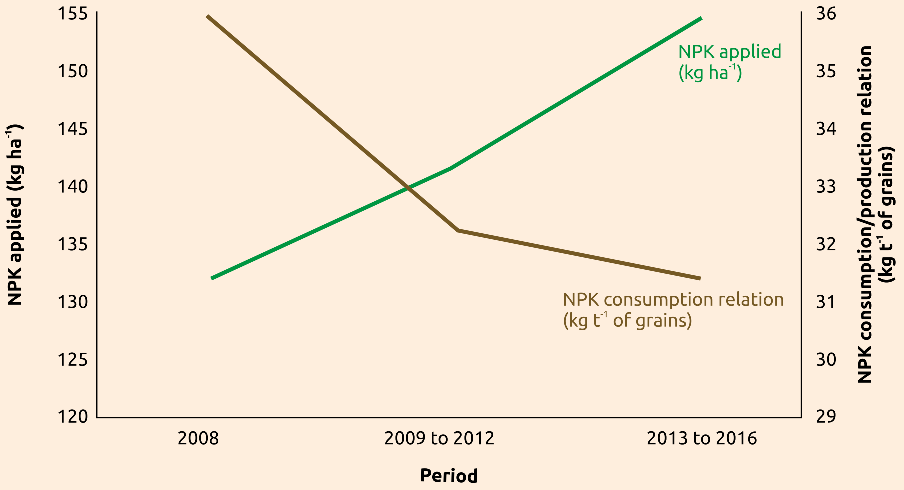

Figure 5. Evolution of the NPK application rate per hectare and the fertilizer consumption/grain production ratio in maize crop in Brazil, from 2008 to 2016.

Source: Adapted from Cunha et al. (2010, 2014, 2018).

weed losses, as a percentage of yield reduction, are between 5% and 10% in developed countries and 20% to 30% in developing countries (FAO, 2006). As for Oerke (2006), the potential loss by weeds is 34%, while the current average loss is around 10%, due to the use of technologies to control these plants. Considering the 10% loss as certain, it can be said that, in the last three harvests, Brazil may have stopped harvesting more than 50 million tons of grain due to the presence of weeds in the field. However, in the most optimistic scenario, considering that national losses are among the lowest in the world, Brazil failed to produce around 12 million tons of grain in the 2019/2020 season.

Reductions in maize yield due to the effect of weeds were estimated worldwide, in 2001 to 2003, between 5% and 19%, with the lowest value found in Europe and the highest rate found in Africa. However, the average loss potential can reach 40% (Oerke, 2006).

The effect caused by weeds can be classified in two ways:

1) Direct, caused by interference in the quantitative reduction of productivity.
2) Indirect, in which the quality of grains harvested at the time of sale is depreciated.

With the introduction of technologies that enabled the farmer to manage weeds in a more economical and practical way, the introgression of genes tolerant to weeds is mentioned. Currently, the effectiveness of weed management through the application of good agricultural practices has reduced production costs in the soybean/maize system without environmental degradation, although occasional cases of infestation of weeds that are difficult to control and of the presence of species that show resistance to herbicides can be seen.

Technologies such as the use of herbicides to desiccate plants, both weeds and cover crops, with a view to implementing the NTS, have contributed to the success of crop rotation and/or succession, thus benefiting producers and the environment. This led to the non-clearing of new areas for maize farming. The soybean/maize rotation occupies 74% of the maize area in Brazil, which was only possible with the use of technologies, in particular, the management of weeds.

Integrated pest management

When the technologies for the integrated pest management (IPM) of maize are correctly used, we observe the land-saving effect from the maintenance of productivity gains achieved in recent decades, including different technologies in the most diverse areas, such as genetics (Bt maize). Pest control is a crucial issue in production, as if it is not well managed and uses the correct methods, it can cause a loss of a good part of the financial investments in the crop, which will directly interfere in the financial return desired by the producers. In extreme cases, the cost of control becomes unfeasible, leading to the abandonment of crops, which, in itself, can represent an increase in the focus of pests for the entire region where this situation occurs.

It is not possible to ignore the fact that, in Brazil, the main maize crop is the second (off-season), which occurs in periods of the year with greater climatic risks, such as water stress. These climatic conditions favor the occurrence of important pests that have caused great damage, such as maize leafhopper (*Dalbulus maidis*), insect-vector of pathogens responsible for maize stunting, whose losses can represent 80% of the crop depending on the climate and the cultivar used. Another important insect in the second crop is *Diceraeus* ssp., especially for maize crops grown after soybeans, where this insect is also a pest. This insect reduces the productive potential of the crop when its attack occurs in the initial farming phase, as it sucks the sap of the new plant, introduces toxins that cause the symptom known as winding of the plant, which is suppressed in the crop. As for the fall armyworm (*Spodoptera frugiperda*) it occurs in all regions where maize is farmed in the country, in the first and second harvests. Its injuries cause economic damage from the germination of the crop and large infestations can reduce the final stand of plants in the crop and also be a gateway for fungi and mycotoxins, which also bring losses. However, the biggest problem caused by the fall armyworm attack is even in the vegetative phase,


Photo: Fábio Gomes da Silva

when it causes defoliation in crops and reduces the productive potential. These insect pests have been managed both using *Bt* transgenic technologies incorporated into cultivars (mainly aimed at the control of caterpillars such as *Spodoptera*), and by the use of chemical insecticides, although in recent years the adoption of biological insecticides has increased.

In 2020, the area farmed with transgenic maize represented 93% of the total area farmed with the cereal (Galvão, 2019; Conab, 2020c). Pereira Filho and Borghi (2020) identified 196 new maize cultivars for different purposes and growing regions; of this total, 131 have transgenic technologies. This large percentage of technology adoption is mainly due to the advantages of use. In a global impact study of the use of genetically modified plants, between 1996 and 2005, on the economic gains of farmers, it was shown that there were significant economic gains for the farmer, with a favorable cumulative total of 27 billion dollars, compared to what would be gained if the *Bt* technology were not adopted (Brookes; Barfoot, 2006). In addition to economic gains, there is a reduction in the application of insecticides, especially those with a broad spectrum (Munkvold et al., 1999; Dowd et al., 2000; Giles et al., 2000; Huang et al., 2002; Colli, 2011).
In Brazil, in addition to the aforementioned benefits, the ease of

crop handling and the improvement of logistics in the field are mentioned as the main advantages of this technology. As one of its disadvantage, the increasing resistance record of the fall armyworm to *Bt* can be cited.

Insect pests can impact the production of maize crops by reducing the stand, reducing the productive capacity of plants, reducing quality and making the commercialized parts of the crop unfeasible. Damage to commercialized structures directly influences crop yields (Pereira et al., 2000; Giolo et al., 2006). In this sense, control measures are adopted in order to minimize such losses. Currently, there is a tendency to adopt control measures with a lesser impact on the environment. However, regardless of which technology is adopted for pest control, it cannot be denied that they represent a good share of the production cost. Only insecticides can represent 5.69% of the production cost. If all pesticides used during the maize cycle are considered, they may represent 16.6% of the crop's production cost in the 2019/2020 season (Conab, 2019). It is estimated that around 60 million dollars are spent annually in Brazil on insecticides for the management of the main maize pests, not counting costs related to the use of *Bt* technologies, which are already built into the seed cost.

Minimizing the destructive potential of insect pests in crops is essential for maintaining productivity. In this context, the Brazilian Agricultural Research Corporation (Embrapa), the Organizações Estaduais de Pesquisa Agropecuária (State Agricultural Research Organizations – Oepas), foundations and universities, in addition to the private sector, work to supply the market with techniques and technologies that are more effective and of a lesser cost. The use of good agricultural practices and the adoption of the MIP, in the conduct of maize crops as a monitoring strategy, can contribute to the optimization of control tools, maintaining productivity, while promoting the sustainability of the agroecosystem and helping to maintain the productive areas over time.

New technologies to increase maize productivity without the need to clear new areas

Agricultural zoning of climate risk

Climatic factors determine agricultural productivity. Climatic adversities such as drought, excess water, frost, hail and rain at harvest are responsible for high loss rates in each region of Brazil. These losses mean a reduction in the farmer's production and income, leading them to add more area to their production in the following seasons. According to the World Bank, Brazil loses annually more than US$ 2.6 billion, about 1% of the agricultural gross domestic product (GDP), in 2015 values, with risks arising from bad weather (Arias et al., 2015).

In order to reduce the risk of crop failure, the agricultural climate risk zoning (ZARC), an instrument of agricultural policies and risk management applied to the agricultural credit and crop insurance programs of the Ministry of Agriculture, Livestock and Food Supply (MAPA), was developed with the objective of minimizing crop losses caused by adverse climatic events.

ZARC identifies areas or regions with satisfactory soil and climatic conditions for the development of crops and times of lesser risk for farming, which ensures the best use of their genetic potential and presents productivity gains combined with reductions in losses (Santos; Martins, 2016). In the case of maize and the maize+brachiaria consortium intercropping, ZARC indicates dates or periods of planting/sowing for the crop in the 1st and 2nd harvests, considering the characteristics of climate, soil types and cycles of cultivars recommended for each municipality in Brazil, in order to prevent climatic adversities coinciding with the most sensitive stages of the crop, minimizing agricultural losses.

The adoption by farmers of the planting windows indicated by ZARC has enabled greater productivity and profitability in the farming of maize and other crops, increasing national production. With the expansion of planting dates and expansion opportunities in already farmed areas, there is a greater supply of grains in the market and, consequently, less pressure to clear new areas, acting as a land-saving effect.

It is important to point out that ZARC is a fundamental element for increasing the planted area of maize in the second crop, in succession to other crops. The review of the information contained in ZARC makes it possible to expand farming in order to reduce losses and increase the viability of maize farming in certain regions, given the restrictive conditions for second crop maize in Rio Grande do Sul and Santa Catarina states (due to the risk of frost), or even water deficiencies at crucial times for the development of maize in autumn/winter in the Midwestern region.

Antecipe System - Intercropping of maize between soybean rows

In terms of future impacts of new technologies that will contribute to the land-saving effect, Embrapa Maize & Sorghum has developed a production system that involves the mechanized planting of the maize crop between the soybean lines, from the R_5 soybean, according to the scale of development proposed by Fehr and Caviness (1977), cited by Farias et al. (2007). This system, called Antecipe (entry with process for trademark registration), is innovative and disruptive for Brazilian agriculture, planned based on knowledge acquired by more than 13 years of research aimed at implementing the maize crop in agricultural regions where the second crop has not yet been fully established. This agricultural production strategy favors the early establishment of maize crop, reducing the risk of loss of productivity in the second crop, enabling the planting of maize in regions with unfavorable climate restrictions from the end of the summer period and beginning of autumn, as well as a likely cost reduction by excluding soybean crop desiccation, since maize is planted between the soybean rows before harvesting. With Antecipe, it will be possible to anticipate the planting of second crop maize by up to 20 days in certain regions of the country, based on the results obtained in research carried out in some regions of the Cerrado biome, described in detail in Karam et al. (2020). In addition, it can be used in regions with greater experience in second crop, allowing the use of longer-cycle soybean cultivars, notably more productive than early ones, without prejudice to the second crop maize yield.

Work began at Embrapa Maize & Sorghum, in Sete Lagoas, MG. Several specialized professionals from different areas of knowledge and professional specialization in agricultural machinery have developed a prototype of a seeder-fertilizer machine that does not exist in the Brazilian market, seeking to carry out the mechanized operation together with planting fertilization between the soybean lines, without mechanical damage, compacting, loss of leaf area or other damage that compromises the productivity of the soybean (patent application BR 10 2020 009566 8, referring to a prototype of a seeder-fertilizer for use in the intercalary system).

A highlight of the system is the fact that maize planting takes place between the soybean rows in a synchronized manner, so that, at the time of the soybean harvest, the maize plants are in vegetative development in the area, up to stage V5. The process of cutting the maize plant by the harvester does not harm its development, since its meristem (growth point) is found below the soil surface, enabling a full

Photo: Décio Karam

physiological recovery of the maize plant under field conditions (Magalhães; Durães, 2006). Thus, after the harvester passes the soybean crop from the area, the remaining maize leaves will be responsible for resuming the crop's productive potential.

This farming strategy promotes considerable gains in succession systems and/or soybean/maize rotation, since:

- It favors the early establishment of the maize crop, reducing the risk of frustration due to loss of productivity.
- It allows for the planting of maize in regions with unfavorable climate restrictions from the end of the summer period to the beginning of autumn.
- It will allow the farming of maize in regions where ZARC limits the farming of this crop in the autumn season.
- It makes it possible to reduce the cost of the soybean crop desiccation operation because, with Antecipe, it will not be necessary to desiccate the soybean using a contact herbicide to anticipate the soybean harvest and allow for the planting of second crop maize within the ideal time.
- It enables an increase in second crop maize productivity through better practices in crop handling.
- It allows for cost reduction with the desiccation operation of post-harvest weeds in the soybean crop.

The role of maize in livestock transformations

According to Martha Júnior et al. (2012), there is a recurrent criticism from some sectors that beef production in Brazil is characterized by low productivity and that it would only be economically viable through the expansion of the pasture area. However, according to the authors, this is an outdated picture of Brazilian beef cattle, being more representative of the period from 1950 to 1975, when productivity gains were only 0.28% per year. According to the study, the situation has changed considerably in recent decades. In the period from 1975 to 1996, the increases in productivity were 3.62% per year, while in the period from 1996 to 2006, the annual increase was 6.64%.

Without such productivity gains, to meet the beef production levels in 2006 with the 1950 productivity, an additional 525 million hectares of pasture area would be needed. Such an area would be 25% larger than the Amazon biome. For the period 1996 to 2006 alone, productivity gains in beef cattle farming saved 73 million hectares of the Amazon (Martha Júnior et al., 2012).

Despite the clear advance in beef cattle productivity, there is still a long way to go for the country to match the productive efficiency of intensive cattle raising in the USA, which are the world's largest beef producer, according to the Associação Brasileira das Indústrias Exportadoras de Carne (Brazilian Beef Exporters Association) (Abiec, 2020). In 2019, this country produced

12.3 million tons of beef carcass equivalent (BCE) from an effective herd of 94.5 million head. The USA produces more meat with fewer head as a result of more intensified livestock farming with greater use of feedlot finishing practice.

In feeding beef cattle is carried out in a much shorter period than in the system only on pasture. By producing more arrobas in less time, the cattle farmer frees the land for agriculture. Thus, intensive livestock systems also have a broad land-saving effect.

In feedlot finishing systems, the maize crop plays a fundamental role in feeding the herd, whether used as forage (silage) or via by-products from other activities, such as Dried Distillers Grains (DDG). DDG is a by-product of the wet milling of maize for the production of ethanol and, due to its high content of protein, it is a substitute for soybean meal in feed composition, constituting a product of great value for livestock.

According to researchers from the United States Department of Agriculture (USDA), the DDG has established itself as a market of great value. Ethanol production in the USA consumed 37% of the maize harvested in the country in 2017/2018, resulting in the production of 38.5 million tons of DDG. In addition to supplying the large domestic livestock market, DDG is increasingly traded internationally.

In 2017/2018, the USA exported 12 million tons of DDG to countries with growing livestock, such as Mexico, Thailand and Vietnam. With the expected growth of ethanol

Photo: Diego Leite (Pixabay)

Photo: Gisele Rosso

production from maize in Brazil, the DDG could become a key element for the transformation of livestock in the country (Olson; Capehart, 2019). The growth of the feedlot finishing practice in Brazil has made a significant contribution to increasing the productivity of beef cattle. According to the Brazilian livestock yearbook produced by FNP Consultoria & Comércio (1999), in 1991 an effective 785,000 head of cattle was finished in feedlots. Recent data provided by Abiec (2020) indicate that the number of cattle confined in Brazil in 2019 reached 6.09 million head, an increase of almost eight times in the period 1991–2019.

Census data from the Brazilian Institute of Geography and Statistics (IBGE, 2017) in relation to the area of pastures in Brazil provide an indication of investment in livestock in recent decades. In this survey, the area of pastures in 1970 and 2017 were, respectively, 154 million and 160 million hectares, but there is a qualitative difference in these numbers. In 1970, farmed pastures represented 19% of the total pasture area, while in 2017, this percentage rose to 70%. As a result, the stocking rate (area/head)[2] went from 1.96 to 0.92 in the period, indicating a lower use of land per head of cattle. Part of this result can be attributed to the fact that the extractive activity of cattle raising

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[2] The literature usually treats the stocking rate as a ratio of number of head per unit of area (hectares) (Martha Júnior; Vilela, 2009; Martha Júnior et al., 2012; Vieira Filho, 2018). However, the Brazilian Institute of Geography and Statistics (IBGE), in the Census of Agriculture (IBGE, 2018), treats this indicator as an area by head ratio. It can be said that the definition in the literature is more intuitive and aligned with the term stocking rate, but as this document used information from the IBGE of the Census of Agriculture, this approach was chosen when analyzing the information.

does not use available technologies to increase the supply of forage.

A production strategy that has contributed to the transformation of Brazilian livestock is called ILPF, which integrates different production systems within the same area. These different integrated production systems optimize land use and can be articulated in four modalities: integrated crop-livestock-forest systems (ICLFS); integrated crop-livestock systems (ICLS); integrated livestock-forest systems (ILFS); and integrated crop-forest systems (ICFS). According to the ICLFS Network Association (Rede ILPF, 2020), the estimated area of ICLFS adoption jumped from 1.87 million hectares in 2005 to 15 million in 2018, with more than 80% of this area using the ICLS modality.

In the ICLS, livestock areas with low productivity and degraded pastures are recovered with grain crops. At this point, maize and soybean stand out, which, in addition to increasing the support capacity of the pasture, also provide food for the herd under feedlot finishing, reducing supplementation costs and the need to acquire energy sources outside the property. According to Martha Júnior and Vilela (2009), the land-saving effect arising from productivity gains in the crop-livestock integration, in particular the livestock component, is seen as a key factor to allow the expansion of food and biofuel production in the country, with minimal pressure on native vegetation.

Integrated Crop-Livestock Systems

In view of the challenge of expanding food and fiber production via increases in productivity, the use of maize in ILCS has proven to be extremely viable from an agronomic, economic and environmental point of view, also contributing to the soil fertility construction process and for the sustainable intensification of conventional production systems. This exploration model has several advantages, such as: improving the physical, chemical and biological properties of the soil; breaking cycles of disease; reduction of pest and weed infestation; and reduction in the cost of recovering and renovating pastures (Vilela et al., 2011).

In most of Brazil, where livestock is based on pasture areas, there is a need to conserve forage/food, especially during the dry seasons of the year, when, due to lack of water or low temperatures, the grass species present they do not produce enough forage to feed the herd. In these production systems, with the use of maize it is possible to obtain large food production on the rural property.

In this process of sustainable intensification within the scope of the ICLS, the maize crop stands out as strategic because of the numerous applications that this cereal has within the agricultural property, whether in animal feed in the form of grains or in green or conserved forage (silage), in human food or in the generation of income through the sale of surplus production.

In this consortium, the main crop used in the ICL has been maize (*Zea mays* L.), either because of its versatility (grain or forage production) or because of its competitiveness in the consortium due to its rapid initial growth and high size, which facilitates competition with other components (ex.: planted pasture) and, in the case of grain harvesting, allows mechanized harvesting to be carried out (Borghi; Crusciol, 2007; Santos et al., 2011; Borghi et al., 2012, 2013; Pariz et al., 2016). Added to this is the existence of a large number of commercial cultivars adapted to different regions of Brazil (Pereira Filho; Borghi, 2020), enabling the farming of this cereal from the Northern to Southern regions of the country and the good availability of post-emergent graminicide herbicides selective to maize. These factors allow to obtain excellent results with the maize + grass intercropping.

Another aspect of ICLS has been the use of annual crops successfully employed in rotation, intercropping and/or succession with perennial tropical forages in areas aimed at recovery or renewal of pastures (Salton et al., 2013; Gontijo Neto et al., 2018). In this sense, the intercropping systems of annual crops, especially maize, with perennial tropical forages have been shown to be quite viable from an agronomic and, mainly, economic point of view (Gontijo Neto et al., 2018).

Thus, technologies such as indirect systems of recovery/renewal of pastures based on the intercropping of plant species have been used by rural producers in the Cerrado region since the early 1980s, with an emphasis on the Barreirão System (Oliveira et al., 1996). With it, it was possible to recover or renovate huge areas with degraded pastures, especially in Central Brazil. It is still used for this purpose today, serving as initial preparation for deploying integrated production systems. Later, for areas where NTS could be used, the Santa Fé System was developed (Kluthcouski et al., 2000), which is based on the intercropping of grain crops, especially maize, with the main tropical forage species, mainly the genera *Urochloa* (*Syn. Brachiaria*) and *Megathirsus* (*Syn. Panicum*). More recently, the Santa Brígida System was developed, with the inclusion of soybean intercropped with maize (Oliveira et al., 2010). In this system, the annual crop presents great initial development performance and exerts high competition on forages, thus avoiding a significant reduction in grain yield.

In different regions of Brazil, the sowing of maize in intercropping with perennial tropical forages, both in the harvest and in the second harvest (second crop), has significantly contributed to increasing the supply of maize by intensifying the use of the same area. It has also enabled livestock production in agricultural areas, increased productivity rates in livestock enterprises, with a consequent extension of the period of use of production factors (Figure 6) and led to a reduction in the pressure

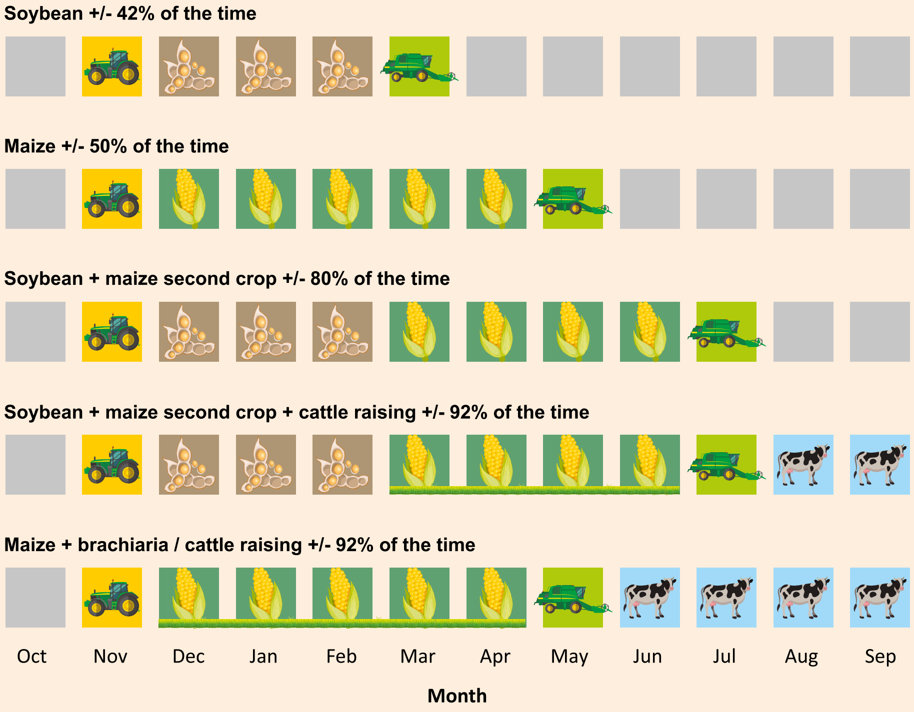

Figure 6. Intensification in the use of production factors due to the use of consortium and succession of activities.

Source: Vilela et al. (2016).

to clear new areas. Thus, in addition to the production of grains of high energy value, the ICLS, through the intercropping of maize with grasses, can increase forage production on the property, either with the production of silage or green cutting. This has been done through the intercropping of these crops with perennial tropical forages and has allowed to increase the support capacity of recovered pasture areas (after farming), making these areas available, with a pasture of excellent nutritional quality, for grazing in the critical period of year (drought).

The integration of agricultural and livestock activities, achieved in a practical way by the succession and intercropping of maize farming with grasses, can thus extend to 92% the time of use of agricultural areas with activities with direct economic return, and, in cases where that the area is used as pasture in the following harvest, this usage time reaches 100% during the year.

Perspectives

The *Stockholm Conference*, held in 1972, initiated a broader discussion of the negative impacts of human action on the environment. However, it was with the massive presence of state authorities at *Rio-92* that countries around the world gave an indication that environmental degradation would become, at some point in the coming decades, a priority issue.

As a result of the large forest extension and deforestation to clear new areas for economic activity, Brazil has been placed in the center of the spotlight on the environmental issue. The use of satellite images by the National Institute for Space Research (INPE), as of 2004, allowed the country to measure and monitor the problem. In this context, strategies and public policies that favor the occurrence of the land-saving effect must be encouraged and disseminated to the general public. Maize crop, due to the intrinsic dynamism of the crop, is a fundamental element within the country's agricultural systems that contribute to the so-called land-saving effect.

In addition to initiatives focused on the environment, the United Nations (UN) has also carried out actions to gather efforts in favor of human development. The UN summit in 2000 set eight international development goals for the year 2015, known as the Millennium Development Goals (MDGs).
In 2015, they continued the initiative and worked with governments, civil society and other partners to establish a new post-2015 development agenda. In this context, the so-called 2030 Agenda was established, with 17 Sustainable Development Goals (SDGs) and 169 targets (Brasil, 2020).

The maize chain and the land-saving effect arising from the adoption of agricultural technologies and practices also have contributions to the SDGs. In this regard, the contribution to SDG 2 (End hunger, achieve food security and improve nutrition and promote sustainable agriculture) stands out; SDG 13 (Take urgent action to combat climate change and its impacts) and SDG 15 (Protect, restore and promote the sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and halt the loss of biodiversity).

Lastly, it is worth noting that several of the technologies linked to the maize crop that resulted in the land-saving effect also received support and incentives through public policies.
The Sectoral Plan for Mitigation and Adaptation to Climate Change for the Consolidation of a Low-Carbon Economy in Agriculture (ABC Plan - Low-Carbon Agriculture), comprising seven programs that contemplate various actions and availability of lines of credit for the adoption and diffusion of many of the technologies presented in the document.

Maize, due to its importance in Brazilian agriculture, has shown a wide possibility of farming and use. The expansion of this crop into farming systems, without the need to clear new areas, made it possible to place Brazil as one of the main producing countries in the world and with prospects for even more expressive volumes, respecting the environment, optimizing the use of natural resources and contributing to the main public policies and conservation goals currently in force in Brazil and in the world.

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Chapter 7

Soybean leadership and productivity records based on technology and intensive land use systems

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Photo: Gabriel Faria

Soybean is the main agricultural crop in Brazil, with the highest Gross Production Value (VBP) and leadership in agribusiness exports. Due to broad intensification, which integrates various area-saving technologies, soybean productivity has grown at an annual geometric rate of 1.9%, since the beginning of the 1960s, which has generated a land-saving effect of 71 million hectares. Furthermore, the intensification of production systems provided an additional land-saving effect of 15 million hectares. Brazil has become the largest producer in the world, occupying only 4.5% of its territory for soybean cultivation. The flow of capital from soybean production has allowed the development of a thriving production chain, with socioeconomic impacts in various regions of the country. First, soybean production has attracted organizations and promoted the economic growth of production centers. Integrated to this evolution in the economic field is the generation of millions of jobs distributed throughout the country. The generation of wealth and the greater flow of people, in turn, attract businesses in other sectors, such as services, commerce and industry, and often also improve basic services provided to the population and people's quality of life.

Introduction

According to the Companhia Nacional de Abastecimento (National Food Supply Company – Conab), Brazil should reach, in the 2020/2021 season, another record in grain production, surpassing 273.8 million tons, cultivating 68.5 million hectares. The highlight is the soybean crop, whose area had an expansion of 4.1% compared to the 2019/2020 season, when the cropped area moved from 36.9 million hectares to 38.5 million hectares, while production grew by 4.3%, from 124.8 to 135.5 million tons. Between the 2016/2017 and 2020/2021 seasons, Brazilian soybean yielded more than 3,400 kg ha^{-1}, whereas, in the 2020/2021 season, the estimated average is 3,523 kg ha^{-1}, 4.25% higher than the average for the 2019/2020 season (3,379 kg ha^{-1}) (Acompanhamento da Safra Brasileira [de] Grãos, 2021).

In 2020, the exports of soybeans in Brazil surpassed 82.9 million tons, higher than the amount exported in 2019, of 74.1 million tons (Brasil, 2021). Even with the advance of exports, crushing may continue its upward trajectory, as pointed out by the forecast of the Associação Brasileira das Indústrias de Óleo Vegetal (Brazilian Association of Vegetable Oil Industries – Abiove), which indicates the processing of 45.5 million tons of soybean in that year, 4.7% higher than the total crushed in 2019 (almost 43.5 million tons). This demonstrates the strength of the markets associated with soybean derived products, especially meats and biofuels (Abiove, 2021).

The total number of jobs created by the soybean production chain between 2000 and 2014 went from 2,352,839 to 3,758,773 (Montoya et al., 2017).

Nationally, this share of jobs represented 3.0% in 2000 and 3.6% in 2014.

In agribusiness, the participation of the soybean production chain is more relevant and with a significant increase in the period, because it represented 7.8% in 2000 and reached 12.1% in 2014 (Montoya et al., 2017). If an increase in employment is projected in proportion to the increase in soybean production in Brazil in 2016 until the current harvest, it is estimated that the sector would be responsible for approximately 4.7 million jobs.

Ways of expanding soybean production

There are two ways to avoid the horizontal expansion of soybean production in Brazil. One of them, purely theoretical, is to stagnate the increase in production. This is unfeasible from a practical point of view, as it depends on market signals, demand and supply of agricultural products, both in the domestic and international markets. The other, viable and desirable, is the vertical expansion of production, either by increasing productivity or by intensifying agriculture, using the same area for different crops/creations in the same agricultural cycle.

Productivity

From a conceptual point of view, it is important to keep in mind the simplified productivity equation:

$$Prod = PG - \{[EB + EAB + (EB \times EAB)]\}$$

in which $Prod$ is the productivity of a crop in a certain location and year; PG is the genetic productivity potential of a cultivar, variety, hybrid of a farmed species, in the absence of stresses; EB represents biotic stresses (presence of pests at levels that affect the crop; quantitative or qualitative deficiency of beneficial organisms); and EAB, abiotic stresses (inadequate temperature, excess or lack of

Photo: A line Macedo

rain, soil acidity, macro and micronutrient deficiency in the soil, compaction, inadequate soil profile, among others).

By analyzing the equation, it is possible to envision two ways to increase productivity. The first one is the increase in the genetic potential of a farmed species, which is obtained through genetic improvement, be it classic or using new biotechnological tools. Furthermore, there is a differential reaction of cultivars in relation to stresses (biotic or abiotic). The same genetic background with high productive potential can receive interesting characteristics to coping with stress. One example is the resistance of soybean cultivars to diseases that can cause high damage.

The second way is the suppression or mitigation of stresses. In the case of biotic stresses, the classic example is the study of the relationship between the presence and intensity of infestation of a particular pest and the resulting reduction in productivity, which is the basis for establishing damage levels or action levels for control. Based on this definition, and with adequate monitoring methodologies, it is possible to develop various forms of pest control. In this sense, classical genetic improvement (resistance or tolerance) is included; the improvement with genetic engineering tools, with the introduction of exotic genes; the escape (seeding season or farming sites); the management of species that are intermediate hosts; physical control (by pheromones, light traps or food); biological control (parasitoids, predators, pest diseases); chemical control or new tools, such as RNA interference (RNAi), among others.

As for abiotic stresses, climatic adversities can be mitigated by appropriate technologies. For example, water deficit, the main abiotic stress of soybeans in Brazil, can be mitigated on a large scale with soil coverage by straw in a No-Tillage System; elimination of surface compacted layers; maintenance of a deep, porous, aerated soil profile, with an adequate proportion of organic matter, high water retention capacity and possibility of root penetration at great depths.

Table 1 shows the geometric growth rates of soybean productivity in Brazil, measured over decades and over the entire period, between 1960 and 2020. It appears that the most significant gain in productivity occurred in the 1990–1999 decade and that, in the last 60 years, Brazil presented a geometric annual rate of increase in soybean productivity of 1.9%, which is highly expressive, and that allows to double the productivity of a crop every 37 years.

Table 1. Geometric rates of the evolution of soybean area and productivity in Brazil.

Season	Area	Productivity
1960–1969	1,159	1,004
1970–1979	1,226	1,009
1980–1989	1,037	1,015
1990–1999	1,014	1,036
2000–2009	1,053	1,011
2010–2020	1,051	1,012
1960–2020	1,091	1,019

Figure 1 shows how much agricultural area was effectively saved by soybean productivity gains in Brazil, according to data collected by CONAB and FAO (FAOSTAT). If the same productivity at the beginning of soybean farming in Brazil (1960) were maintained, the area that would be necessary to obtain the same production of the 2019/1920 season would be 195% greater than the current area. In these terms, the area-saving effect due to the increase in soybean productivity since the 1960s was approximately 71 Mha.

Since the 2008/2009 season, the Comitê Estratégico Soja Brasil (Soybean Brazil Strategic Committee – CESB) has annually held the Desafio de Máxima Produtividade de Soja (Challenge of Maximum Soybean Yield) annually. Its objective is to obtain information from registered producers (6,000 producers in the 2019/2020 season), in order to verify the productivity obtained, the profitability earned and the eco-efficiency of the producers with the highest productivity, in each geographic region of Brazil.

From the standpoint of the international market, it is becoming more and more transparent that it is not enough to produce, it is necessary to be sustainable. Therefore, CESB uses the eco-efficiency methodology, which is measured by a weighted and standardized algorithm that takes into account the following criteria: impacts on climate change, water consumption, freshwater eutrophication, marine eutrophication, acidification, resource depletion of mineral and fossil resources, ozone layer depletion, photochemical ozone formation, human toxicity, and land conversion and use.

Table 2 shows the productivity obtained by the ten Brazilian soybean producers with the highest productivity

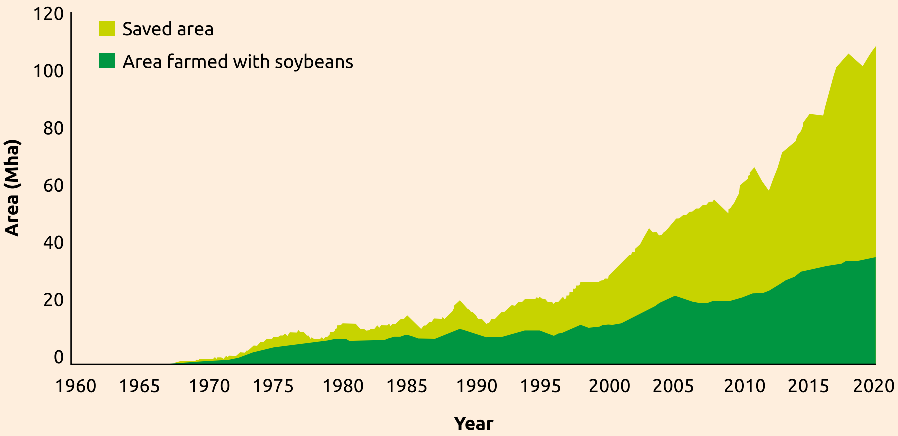

Figure 1. Area effectively farmed, compared to the area saved, if productivity remained constant over the period.

Source: Conab (2020).

Table 2. Soybean productivity (kg ha^{-1}) obtained by the ten producers with the highest productivity, in the editions of the Maximum Productivity Challenge, of the Soybean Brazil Strategic Committee (CESB), compared to the average Brazilian productivity.

Average placement	**Season**												
	2008/ 2009	**2009/ 2010**	**2010/ 2011**	**2011/ 2012**	**2012/ 2013**	**2013/ 2014**	**2014/ 2015**	**2015/ 2016**	**2016/ 2017**	**2017/ 2018**	**2018/ 2019**	**2019/ 2020**	**Average**
1st	4,968	6,504	6,036	6,522	6,630	7,038	8,508	7,204	8,946	7,621	7,433	7,129	7,045
2nd	4,896	5,526	6,030	6,186	6,582	6,594	7,632	6,891	7,332	6,782	7,410	7,118	6,582
3rd	4,878	5,310	5,976	6,156	6,570	6,570	7,608	6,619	6,636	6,554	7,274	7,008	6,430
4th	4,848	5,238	5,940	5,928	6,186	6,534	7,374	6,554	6,498	6,537	7,179	7,001	6,318
5th	4,836	5,154	5,922	5,562	6,168	6,480	7,302	6,548	6,384	6,391	7,106	7,001	6,238
6th	4,590	5,082	5,712	5,436	6,132	6,432	6,804	6,422	6,348	6,389	7,043	6,986	6,115
7th	4,536	5,028	5,598	5,394	6,126	6,384	6,798	6,306	6,288	6,381	7,034	6,870	6,062
8th	4,470	5,004	5,454	5,394	5,994	6,282	6,744	6,227	6,270	6,360	7,016	6,828	6,004
9th	4,374	4,998	5,340	5,358	5,958	6,198	6,624	6,066	6,228	6,337	6,852	6,732	5,922
10th	4,260	4,992	5,250	5,334	5,910	6,174	6,618	6,005	6,156	6,264	6,827	6,716	5,875
Average (A)	**4,666**	**5,284**	**5,726**	**5,727**	**6,226**	**6,469**	**7,201**	**6,484**	**6,709**	**6,562**	**7,117**	**6,939**	**6,259**
CONAB (B)	**2,629**	**2,927**	**3,115**	**2,651**	**2,938**	**2,856**	**3,025**	**2,878**	**3,392**	**3,507**	**3,337**	**3,379**	**3,379**
A/B (%)	**78**	**80**	**84**	**116**	**112**	**125**	**140**	**122**	**100**	**99**	**112**	**114**	**107**

A: average of the top ten placed in the Challenge; B: CONAB average for the same harvest.
Source: Comitê Estratégico Soja Brasil (2020) and Conab (2020).

(regardless of region), according to the CESB Maximum Soybean Productivity Challenge, compared to the average productivity calculated by CONAB, for the same season. It is noteworthy in this table that, in the average of the last 12 years, the ten best placed producers in the challenge, produced 107% above the Brazilian average, measured by CONAB.

Table 3 shows the average soybean productivity of producers placed between 1st and 100th positions in the CESB Maximum Productivity Challenge, compared with the average productivity of Brazilian soybean producers, according to CONAB. In the average of the last 12 years, these producers obtained yields 75% higher than those attained by the group of Brazilian producers, according to CONAB.

The above illustrates two aspects that deserve to be analyzed. The first of them is that Brazil has soybean production technology that significantly increases the crop's yield, with technologies already available to the producer. The second aspect is an enormous challenge, which includes a great opportunity. The technology is available, but not fully used by soybean producers. The solution lies in broad and mass adoption, the result of technology transfer processes backed by technical assistance, and supported by public policies to encourage the increase of sustainable productivity, as a way to reduce the expansion of the country's agricultural frontier. In other words, Brazilian soybean has experienced extraordinary increases in productivity, but there is technology already available to increase it further.

Table 3. Soybean productivity (kg ha^{-1}) of the 100 best positioned producers in the Maximum Productivity Challenge, of the Strategic Committee Soybean Brazil (CESB), compared with productivity Brazilian average.

Productivity	Season												Average
	2008/ 2009	2009/ 2010	2010/ 2011	2011/ 2012	2012/ 2013	2013/ 2014	2014/ 2015	2015/ 2016	2016/ 2017	2017/ 2018	2018/ 2019	2019/ 2020	
CESB (kg ha^{-1})	4,666	4,547	4,278	4,285	5,060	5,199	5,685	5,584	5,708	5,961	6,172	6,305	5,288
Brasil (kg ha^{-1})	2,629	2,927	3,115	2,651	2,938	2,856	3,025	2,878	3,392	3,507	3,337	3,379	3,053
A/B (%)	77.5%	55.3%	37.3%	61.6%	72.2%	82.0%	87.9%	94.0%	68.3%	70.0%	84.9%	86.6%	73.2%

Source: Comitê Estratégico Soja Brasil (2020) and Conab (2020).

Agriculture intensification

Agricultural intensification, represented by successive crops cultivated in the same area, in the same agricultural cycle, is one of the important strategies to contain the horizontal expansion of production. This production system is only possible in tropical and subtropical regions, where there is no thermal restriction for farming, although there may be water restriction, circumvented by the use of appropriate technologies, such as agro climatic zoning, well-conducted No-Tillage System, use of species and cultivars more tolerant to water deficit and irrigation.

The most striking example of agricultural intensification involves the production of soybeans in the spring season and maize as a second crop, sowed in the summer. Moreover, in many Brazilian regions, there is the possibility of a sequence of soybeans (sowed in the spring), followed by maize intercropped with grass (sowed in the summer) and a third activity represented by grass grazing in August and September, popularly called the third beef harvest. Historical series show annual advances in crop succession within the same agricultural cycle, usually with soybean being the first crop (sown from the end of September), followed by maize, cotton, common beans, cowpea, among other crops.

Figure 2 illustrates the evolution of the area under maize cultivation in Brazil, distributed between the first and second harvest. The continuous

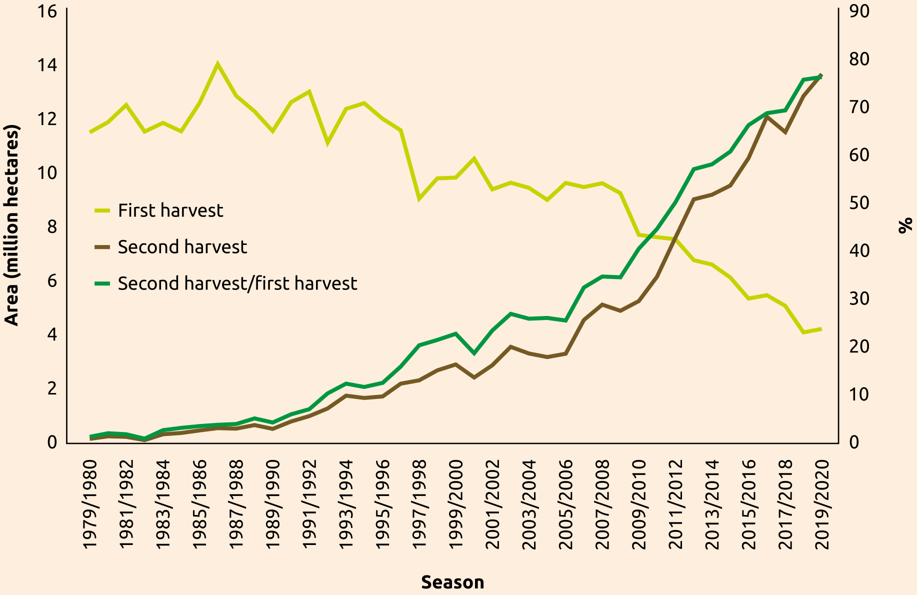

Figure 2. Area farmed with maize in the first and second harvests and percentage of the area of the second harvest over the total area farmed with maize.

Source: Conab (2020).

farming advance of the second harvest in relation to the first is shown by the percentage of the second harvest area over the first one. In the 2020/2021 season, 14.8 Mha of maize were cropped in the summer (second harvest) versus 4.3 Mha in the classic spring cultivation. In other words, these 14.8 Mha clearly represent the area saved, preventing expansion of the agricultural frontier, with probable deforestation.

Figure 3 shows the comparative evolution of productivity for each of the harvests, demonstrating the farmer's learning experience over time, so that, since the 2000–2010 decade, the yields between the two harvests are equivalent. Productivity equivalence is essential for the continued expansion of agricultural intensification, as this is closely related to the profitability of the agricultural cycle and profitability is closely associated with productivity.

In relation to cotton, of the total 1,413,100 ha farmed in the 2020/2021 season, about 1 Mha (70%) was cultivated as a second crop, after the soybean harvest. Thus, with only maize and cotton crops, savings from agricultural intensification, in the 2019/2020 season, amounted to 15.8 Mha. Considering other crops, the area saved due to the intensified use of agricultural areas is estimated to be 16 Mha.

In conclusion, the area-saving effect combines 71 Mha (increase in soybean productivity since the 1960s) + 15.8 Mha (intensification of production systems) = 86.8 Mha.

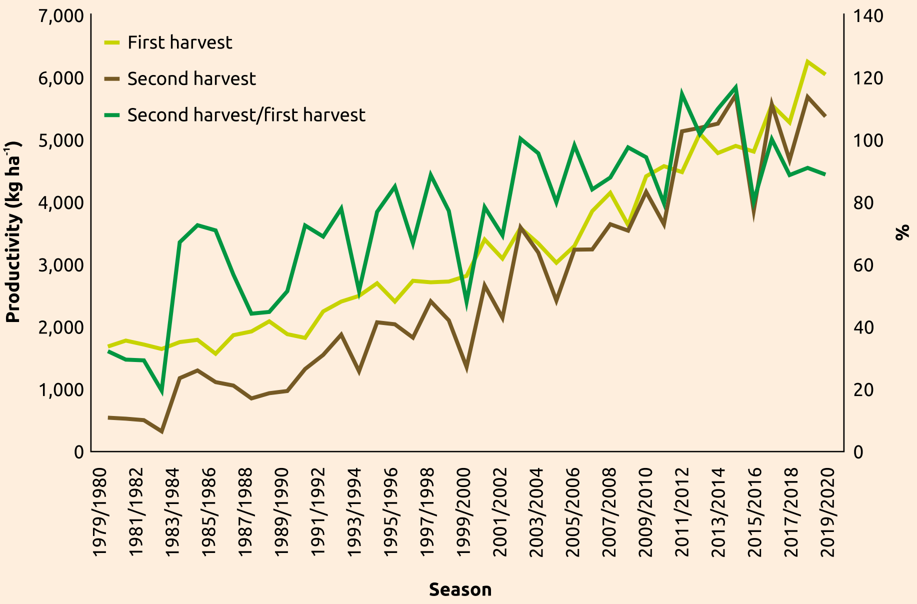

Figure 3. Maize yield in the first and second harvests and percentage of yield in the second harvest in relation to the first harvest.

Source: Conab (2020).

Description of land-saving technologies

The main technologies that allowed the increase in soybean productivity in Brazil and the intensification of production systems are presented below, with the direct consequence of reducing the demand for the clearing of native areas for soybean farming. It is emphasized that it is complex to determine the isolated contribution of each technology to increase productivity or intensify production systems, since the effects of the interactions of technologies determine such gains. An example is the synergy between soybean genetic improvement and the No-Tillage System to make the soybean/maize second harvest succession viable. Additionally, there are several technologies that have contributed to the increase in soybean yield and, at the same time, to the intensification of production systems, such as, for example, the integrated crop-livestock system.

Agricultural zoning of climate risk

A study by Embrapa, based on data from the Programa de Garantia da Atividade Agropecuária (Agricultural Activity Guarantee Program – PROAGRO), found that more than 90% of crop losses in grain species occurred due to deficit or excess water. For the southern states of the country, the importance of the thermal factor was also evidenced, mainly due to the high probability of frost. Based on these findings, the Ministry of Agriculture, Livestock and Food Supply (MAPA) instituted the climate risk agricultural zoning (ZARC) in 1996 as a public policy instrument to reduce agricultural losses caused by climatic factors.

ZARC, in addition to considering the risks of occurrence of climatic adversities, also assesses the environmental need of each agricultural crop, in terms of physiology, cycle, and other factors considered important (Farias et al., 2001). In addition, soil types are taken into account in terms of water storage capacity. In this context, the observance of the provisions of the ZARC, in addition to being a great inducer of the use of technologies, allows reducing the water risk and maintain high productivity with greater stability, decreasing the demand for additional area and disciplining the occupation of the area presented occupied by agriculture.

Genetic improvement

Soybean cultivars with greater productive potential are continually being developed, which incorporate productivity gains over time. This was reconciled with the reduction of the cultivar development cycle and greater flexibility in the sowing time. In other words, the genetic improvement of the oilseed contributed decisively to increasing crop productivity and intensifying production systems, as it allowed for early sowing and reduced the time the crop remains in the field, providing opportunities for the inclusion of other crops in the same agricultural cycle, such as maize, cotton and sorghum, for example. Currently, there is no consistent paper work in Brazil to estimate the genetic gains achieved in recent decades, considering different regions and groups of relative maturity of cultivars.

However, only the expansion of genetic potential is not an isolated goal, important advances have also been made regarding genetic resistance to the following pathogens causing soybean diseases: frogeye spot (*Cercospora sojina*); bacterial pustule (*Xanthomonas axonopodis* pv. glycines); stem canker (*Diaporthe aspalathi*); phytophthora root rot (*Phytophthora soybeane*); oidium (*Microsphaera diffusa*); brown stem rot (*Cadophora gregata*); common mosaic virus (*Common mosaic virus* – SMV); stem necrosis virus (*Cowpea mild mottle virus* – CPMMV); target spot (*Corynespora cassiicola*) among others. It is important to emphasize that Embrapa's soybean breeding program is strongly active in genetic resistance to these diseases.

In the last decade, it is worth mentioning the great advance in obtaining soybean cultivars with resistance to the fungus *Phakopsora pachyrhizi*, which causes Asian soybean rust, the main disease of the crop. Currently, there are several soybean cultivars on the market that are resistant to this disease, especially with Rpp genes. Embrapa has cultivars with this characteristic, trade under the general brand "Shield".

Cultivars incorporating resistance to nematodes, such as the soybean cyst nematode (*Heterodera glycines*) have also been developed; gall nematodes (*Meloidogyne incognita* and *Meloidogyne javanica*); root lesion nematode (*Pratylenchus brachyurus*); and the reniform nematode (*Rotylenchulus reniformis*). In many regions, the use of nematode resistant cultivars is decisive to make the crop economically viable.

Regarding resistance to pest insects, there is currently a vast portfolio of

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cultivars with resistance to several caterpillars that are defoliators of the crop, through the introduction of genes from the bacteria Bacillus thuringiensis (*Bt* cultivars). Additionally, Embrapa has an exclusive platform, which grants tolerance to the bugs that attack soybeans, known as "Block" technology, backed by classic genetic improvement.

Regarding weeds, there are several cultivars on the market with the glyphosate tolerance gene, which allowed more effective control of the majority of the weed species, in addition to facilitating control. In this context, genetic improvement also had a great contribution in reducing biotic stresses in the crop.

Sowing technologies and seed quality

The use of a suitable spatial arrangement of plants for each soybean cultivar is important to maximize grain yield (Balbinot Junior et al., 2018).The spatial arrangement is basically defined by plant density, spacing between rows and uniform distribution of plants in rows. The spacing range that has shown the best results is 0.4 m to 0.6 m. Some cultivars require high population density, for example 400,000 plants per hectare, while others need low populations, such as 150,000 plants (Ferreira et al., 2020).The correct adjustment of density for each cultivar, region and sowing time is relevant to achieving high yields, associated with the reduction of phytosanitary problems. The use of sowing machines with high precision in the distribution of fertilizers and seeds promotes proper installation of the crop, with greater chances of obtaining high yields.

For the establishment of a soybean crop with an adequate plant population, it is essential to use seeds with high vigor and sowing machines with high precision. High vigor seeds result in the production of plants with high agronomic performance, increasing productivity, both per plant and for the crop. Researches prove that the use of seeds with high vigor promotes productivity gains greater than 9%, compared to seeds with low vigor (Scheeren et al., 2010).

Chemical analysis of soil and tissue

In Brazil, most soils are acidic and of low natural fertility, and careful fertilization is the main tool for increasing soybean productivity. Therefore, fertilization must be carried out based on technical criteria that allow the correct assessment of soil fertility and provide the efficient use of fertilizers, an expensive and largely imported input, to meet the nutritional needs of the plants and maximum efficiency economic for the producer.

The evaluation of soil fertility is based on the identification of nutritional factors that limit the achievement of high yields, through chemical analysis of the soil, which can be complemented by leaf diagnosis. The chemical analysis of the soil is the main tool for assessing fertility and enables decision making for the practice of liming and for the recommendation of fertilization. Leaf analysis is a complementary possibility to the interpretation of soil analyzes and capable of identifying deficiencies or excesses of nutrients that would be compromising the high productivity of soybeans. From the leaf analysis, it is possible to verify if the plants are adequately absorbing the nutrients available to them in the soil.

The careful collection of soil samples, regardless of the appearance of symptoms in the plants, the cautious analysis and accurate interpretation of the results is one of the first steps towards the correction of soil fertility problems and meeting the nutritional needs of soybeans, enabling the expression of the productive crop potential.

Studies developed by Embrapa Soybean indicate the adequate levels of nutrients in the soil and leaves, allowing the precise identification of possible nutritional imbalances or correction of fertility. Based on these values, recommendation tables for correctives and fertilizers were developed, which make it possible not only to correct possible problems, but also to increase productivity, in a sustainable basis.

Based on the analysis results, the fertilization recommendations are found on the nutrient availability classes, indicated by the ranges of levels determined in the soil and tissue analysis, determined in calibration and response studies to fertilization (Oliveira Junior et al., 2010a).

Photo: A line Macedo

Regarding potassium (K), a nutrient routinely involved in the appearance of nutritional problems and reduced productivity, special studies were specifically focused on the problem. On average, soybeans demand between 20 kg and 25 kg of potassium (K_2O) for each ton of grain (Oliveira Junior et al., 2020). Without proper fertilization management, there is a reduction in nutrient stocks in the soil and, consequently, there is a reduction in crop yields in the area.

To assist in the identification of potassium deficiency in soybean plants, the Fast-K method was developed (Oliveira Junior et al., 2019), which allows the rapid assessment, under field conditions, of the potassium supply deficit, allowing the correction of the problem before it affects the soybean yield. The advantage of this technology compared to leaf analysis is the most expeditious and accurate way to identify the problem in field conditions and the possibility of correction during the harvest.

Another powerful tool, in addition to the interpretation tables of nutrient content in leaves and Fast K, is the regionalized Diagnosis and Recommendation Integrated System (DRIS)[1], which assesses not only the adequate concentration of nutrients, but also the nutritional balance between them. This way, it identifies the nutrients that most affect productivity, due to deficiency or excess, and then it sets up more efficient fertilization strategies, considering the high value of fertilizers in the production cost, in addition to the potential for losses or environmental contamination.

Therefore, the proper diagnosis of soil fertility and the nutritional status of soybean plants allows for increased productivity in conditions where the nutrient content is low, regarding the maintenance of high production levels under conditions where the nutrient content is adequate or high, leading, in both cases, to greater vertical efficiency of the production system, which saves the clearing of new areas with native vegetation.

No-Tillage System

The use of No-Tillage System (NTS) advocates the sustainability of production systems, since its emergence in Brazil, in the early 1970s. It is based on the reduction of soil mobilization, mainly through the elimination of primary preparations, on permanent soil coverage by crops or plant residues and on crop rotation (Moraes et al., 2017). Intensified agriculture with a focus on grain production has reduced the use of rotation and favored crop succession, which is not ideal. Nevertheless alternative ways emerged to increase the diversification of farmed species, without giving up commercial crops, through intercropping of ground cover species with crops of commercial interest and the farming of cover crops in periods not occupied by commercial crops. Thus, the NTS contributes to maintaining the productive capacity of soils over the years, mainly by increasing soil organic carbon (organic matter).

Organic matter is responsible for several chemical, physical and biological attributes of the soil, ensuring fertility under the nutritional aspect of plants, water storage in the soil and supply of crops through the effects on soil structuring, and high microbial activity and diversity in the soil, which also favors grain production. At the beginning of the adoption of the NTS, soybean yields were comparable to conventional tillage, but stood out in terms of conservation; consequently, after about 6 years of adoption, soybean

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[1] Available at: www.embrapa.br/soja/dris.

Photo: Paulo Odilon Ceratti Kurtz

productivity in NTS becomes higher (Franchini et al., 2012). These authors verified that, after 20 years of conducting the NTS, soybean productivity was about 50% higher than conventional soil preparation. In other words, NTS is an essential technology for obtaining high soybean yields in Brazil, both in the subtropical and tropical portions.

The NTS is the dominant soil management system for grain production in Brazil, occupying almost 70% of the area farmed with grains and more than 90% of the soybean area (Gazzoni; Dall'Agnol, 2018). According to the Federação Brasileira de Plantio Direto na Palha (Brazilian No-Till Farmers' Federation – FEBRAPD), more than 33 million Mha have adopted this form of management. The absence of soil tillage and the maintenance of vegetation cover on the soil corroborate the practices of soil conservation. The NTS is a fundamental cropping system to enable farming in tropical and subtropical regions, allowing crop intensification and good conditions for crop development, with a minimum soil degradation. This way, it has leveraged Brazilian agriculture, especially in the last 4 decades. The problems of erosion in agricultural soils were considerably reduced, contributing to sustainability, generating savings in correctives, fertilizers and soil preparation operations, which are highly expensive with consumption of fossil fuels and carbon dioxide emissions. In addition, it significantly reduces production costs, especially as it consumes less fuel.

Another great benefit arising from the adoption of the NTS in Brazil has been the possibility of intensifying production systems. In most of the grain-producing areas, the second harvest has only been made possible because of the operational facilitations generated in the NTS environment. In this context, it is possible to harvest and sow the same area simultaneously. Sowing in unprepared soil increases the time available in terms of soil moisture, in addition to eliminating soil preparation operations that preceded the sowing of a new crop. Taking as a reference the two main crops in Brazil today – soybean and maize – the first is predominantly farmed in the spring, followed by maize as the second crop, which currently accounts for 75% of national production. The large growth of the second maize cultivation was due to the facilitations created by the NTS in terms of operationalizing the production system. In this context, the NTS has contributed to the achievement of high soybean yields and to the intensification of production systems, reducing the pressure to clear new areas.

Integrated Crop-Livestock System

The Integrated Crop-Livestock System (ICLS) is a production strategy that integrates annual crops and livestock, in the same space, as a consortium, succession or rotation, and seeks to enhance the synergy between the livestock and crop components (Balbinot Junior et al., 2009). Integrated production systems such as the ICLS promote greater crop diversification in the environment while intensifying agricultural activities in the same area. Among the objectives of this system are: to recover the productive capacity of the soil; intensify land use; reduce demand for additional land; make production alternatives available for low-carbon agriculture; contribute to reduce deforestation and improve the technological and managerial level of technicians, producers and employees.

The ICLS presupposes the vertical growth of the national production of soybean, other grains and animal products. This is because it promotes optimization of land use and the resources needed by plants – water, light and nutrients (Balbinot Junior et al., 2009). But the integration of activities brings other benefits to the environment, starting with the increase in the diversity of species farmed in the production system, and thus creating opportunities for the presence of residues on the soil or living plants for a longer time throughout the year. The presence of grazing animals, acting as a nutrient and energy cycling element, increases the biological activity in the soil, which is highly desirable. Integrated systems with good management promote accumulation of organic matter in the soil, a fundamental factor for increasing crop productivity, while contributing to a reduction in carbon dioxide emissions into the atmosphere (Cordeiro et al., 2015).

In the alternating sequence of land occupation, forage species can be used that improve the soil profile and are part of the ICLS. This system, in addition

Foto: Gabriel Rezende Faria

to other benefits, increases soybean productivity. Plant biomass – roots and residues – generates a favorable environment for the activity of soil biota (macro and microorganisms), which, in turn, together with the root system of grain or forage-producing plants, promotes soil structuring, giving rise to biopores and aggregates, which consequently improve water storage, generating a favorable environment for gas exchange and nutrient supply, increasing the productive capacity of the soil (Cecagno et al., 2016). The synergy between the ICLS and the NTS has decisively contributed to the achievement of high soybean yields and intensification of production systems in Brazil.

Biological nitrogen fixation, growth promoting microorganisms and soil phosphate solubilizers

The Brazilian soybean production uses inoculation with nitrogen-fixing bacteria (rhizobia), dispensing with the use of mineral nitrogen fertilizer. This is the most successful case in the world of using microorganisms in agriculture (Hungria; Mendes, 2015). The trade in inoculants increased from about 23 million doses in 2010 to 78 million doses in 2018, more than the increase in the area occupied by soybean crops.

Most of the inoculants produced in Brazil – 87.5% – are used in soybean cropping, resulting in an estimated adoption between 60% and 90%, depending on the region. Inoculation with Bradyrhizobium spp. results in an average productivity gain of 8% and coinoculation (*Bradyrhizobium* spp. + *Azospirillum brasilense*) allows for an increase of 16% in relation to the absence of inoculation (Hungria et al., 2013a). These values were also observed in production areas in partnership with the Empresa Paranaense de Assistência Técnica e Extensão Rural (Paraná State Technical Assistance and Rural Extension Company – Emater-PR) (Nogueira et al., 2018; Prando et al., 2019). This increase represents more production in the same area, using biological technologies, low cost and without negative environmental impact.

Considering the soybean area in 2017, the average grain yield and greenhouse gas (GHG) emissions that would be required for the synthesis and use of mineral nitrogen fertilizers, 62 Mt of CO_2 equivalent were not released into the atmosphere (Hungria; Nogueira, 2019). The replacement of fertilizers by biological N fixation reduces not only GHG emissions, but also the environmental contamination of running and groundwater with nitrites and nitrates (Hungria; Mendes, 2015), generating savings of approximately US$12.5 billion for Brazilian farmers.

Recently, Embrapa launched the BiomaPhos product, containing the BRM 119 strains (*Bacillus megaterium*) and BRM 2084 (*Bacillus subtilis*), two bacteria capable of increasing the availability of phosphorus to plants through the production of organic acids that mobilize phosphorus from precipitated forms in minerals, and phytates, which mobilize phosphorus from organic matter (Sousa et al., 2020). This is another technology based on growth-promoting microorganisms that helps to increase productivity, reducing the pressure to clear new areas.

Weed management

Weeds constitute an important biotic stress in soybean crop. For example, only 4 plants m-2 of sourgrass (*Digitaria insularis*) reduce grain yield by 25% (Gazziero et al., 2019). In the last 4 decades, various preventive, crop and chemical weed management practices have been developed and disseminated in production systems involving soybean farming. One of the main strategies is to sow soybeans in a No-Tillage System with a high amount of straw, which inhibits the emergence of a series of positive photoblastic weeds (Balbinot Junior et al., 2008). This strategy, together with preventive measures so that new invasive species do not infest controlled areas, has a high impact on the rational management of weeds.

In Brazil, currently about 95% of the soybean area is farmed with soybean resistant to the herbicide glyphosate (RR or RR2), which allows to control weeds using a non-selective herbicide, with a broad spectrum of control. This strategy greatly facilitated the control of weeds in soybean crops and contributed a lot to reduce yield losses due to this biotic stress. However, the prolonged and frequent use of glyphosate over the years has led to the selection of weed biotypes resistant to this herbicide, such as horseweed (*Conyza* spp.), sourgrass and ryegrass (*Lolium multiflorum*), among others. To overcome the problem and to avoid the development of new cases of resistance, Embrapa advises producers on the proper management of the control of invasive plants, involving the use of different crop and preventive techniques, as well as the alternation of herbicides and herbicide-resistant genetic material. These measures are essential to protect the productive potential of the soybean crop and for the use of intensive systems, without serious problems of weed infestation and herbicide residual that compromise subsequent crops.

Insect pest management

Soybean crop is attacked by several species of pests, which, when not properly controlled, can drastically reduce or even make its production unfeasible. (Bueno et al., 2012). Thus, Manejo Integrado de Pragas da Soja (Integrated Soybean Pest Management – MIP-Soybean) is the technology developed by Embrapa Soybean, in partnership with different universities and research institutions (such as the Instituto de Desenvolvimento Rural do Paraná – Rural Development Institute of Paraná, IDR-PR, for example), with the main objective of producing so as not to impose damage to the environment or its biodiversity, as well as not to reduce the quality or economic value of the soybean produced (Torres; Bueno, 2018; Bueno et al., 2021). The MIP-Soybean technology is based on three pillars namely: 1) pest monitoring, their damage and their natural enemies; 2) the levels of pest damage; and 3) the use of different management strategies. Therefore, this technology, when correctly adopted, allows reducing productivity losses caused by pests with a rational use of insecticides, associated with other management tools such as biological control or the use of more resistant soybean cultivars (Bueno et al., 2021). With the application of MIP-Soybean it is possible to avoid the occurrence of biotic stresses caused by pests, eliminating the restriction resulting from the damage of these harmful insects. This preserves the expression of the crop's productive potential, reducing the demand for additional farming areas to maintain the same production.

Soybean and maize represent around 85% of grain production in the country. Soybean is usually grown as a first crop in the spring/summer, followed by maize as a second crop in autumn/winter, and occasionally wheat as a second or third crop. The intensive use of the area, which also ensures greater production, favors the multiplication of polyphagous pests and becomes only economically and environmentally viable thanks not only to the adoption of MIP-Soybean, but to this entire production system. Therefore, this technology is a key component for achieving sustainable food production, protecting crops against pests and, at the same time, maintaining environmental quality through integrated and ecologically correct crop management practices. (Bueno et al., 2021). Thus, MIP-Soybean provides high yields, with reductions in environmental impact and production costs, as it generates savings of up to 50% with insecticides (Conte et al., 2019a).

In Brazil, the study and development of this technology took place in the late 1960s and early 1970s (Bueno et al., 2021) and was strengthened with the foundation of Embrapa Soybean in 1975, its main sponsor. Periodic studies and research are carried out at the institution aiming at the development of new management tools, in addition to the constant updating of the MIP-Soybean as a whole, in view of the characteristics of the production systems and the changes in the panorama of pests in crops.

Disease management

Among the main factors that limit the achievement of high yields in soybeans are diseases (Hartman et al., 2015). The economic importance of each disease varies from year to year and from region to region, depending mainly on the climatic conditions of each crop, but there are several diseases that can make the soybean crop unfeasible if management measures are not adopted (Godoy et al., 2016a). Controlling diseases through genetic resistance is the most efficient and economical approach. However, for a large number

Photo: Ken Ritchie (Pixabay)

of them, there are no resistant cultivars or its number is limited. (Godoy et al., 2015). Therefore, the economic coexistence with diseases depends on the action of several factors of an integrated crop management system.

Recommendations for properly managing soybean diseases include: a) crop rotation, to reduce the population of pathogens that survive from one crop to another in crop residues (Almeida et al., 2001; Debiasi et al., 2016; Acharva et al., 2020); b) avoid soil compaction to promote good root development and reduce water accumulation in rainy periods (Torres et al., 2010); c) eliminate voluntary soybean plants and not to cultivate soybean in the off-season (sanitary empty), in order to reduce the population of the Asian rust fungus (Godoy et al., 2016b); d) use cultivars resistant to diseases that occur at the farming site and certified seeds, of safe origin (Costamilan et al., 2017); e) use early cultivars, at the beginning of the recommended season for each region (Godoy et al., 2016b); f) maintain adequate soil fertility, which provides less disease-sensitive plants (Oliveira Junior et al., 2010b); g) seed treatment is recommended to prevent the spread of diseases to new growing areas and to guarantee emergency in case of short spells after sowing (Godoy et al., 2016a; Costamilan et al., 2017); and h) when necessary, use fungicides, according to the history of the crop and monitoring carried out since the emergence of soybean (Godoy et al., 2016b). The integrated adoption of these management strategies has ensured adequate protection for Brazilian soybeans, allowing the achievement of high yields.

Advances in mechanization from seeding to harvesting

Along the last 4 decades, there have been significant improvements in sowing machines, sprayers and harvesters, allowing for proper installation of the crop, efficient phytosanitary control and reductions in harvest losses. These advances directly affect soybean productivity. The increase in operational capacity also facilitates the conduction of intensified production systems, as it allows harvesting and seeding to be carried out quickly.

With regard to harvest losses, the Programa de Redução das Perdas de Grãos na Colheita de Soja (Program for the Reduction of Grain Losses in the Soybean Harvest – PRPGCS), coordinated by Embrapa Soybean, is an institutional action that encourages monitoring of soybean grain losses that occur during the process of harvest, using the technological innovation known as "Embrapa's Loss Measuring Cup". Through this tool, it is possible to measure how much of the production is not being collected by the harvester and determine if the total losses are within a maximum tolerance level of one bag of 60 kg ha-1, above which it is considered as preventable waste and that, barring uncontrollable conditioning causes mainly of climate, in most cases could be avoided.

The grower must ensure permanent and qualified training of the operators of its harvesters, or of the rented machines. In both cases, it is important that the maintenance of the equipment had been carried out in a timely manner, in an adequate manner, according to the manufacturers' recommendations and by skilled professionals.

At harvest time, it is important to monitor the areas and assess losses during operations, which allows for timely correction of noncompliances. Care must also be taken to ensure that the grain moisture is within the ideal range, and that the harvest is carried out in drier periods, facilitating the harvester's performance. Soybean plants must be devoid of green leaves or stems, as well as the presence of invasive plants vegetating in the area to be harvested. Lastly, there is a range of operating speed that represents the best benefit/cost, as outside this range it decreases harvester performance or increases crop losses.

The most recent result of the importance of measuring losses in the soybean harvest was obtained by EMATER, when carrying out a survey in the 2018/2019 season (Conte et al., 2019b), registering an average loss rate of 1.2 bags per hectare in the state of Paraná. The additional 0.2 bag is a value that is slightly above the tolerance level established by Embrapa Soybean – and that represents a waste of 10.2 kg ha^{-1} soybeans; it may seem insignificant, but when multiplied by the 5.4 Mha sown in Paraná in the 2018/2019 season year, it represents almost 925,000 bags of soybean.

Other important information in the context of the soybean production chain

Logistics

The integration of transport modes is paramount, since the production needs to be transported from the production site to its destination, either to a domestic industry or to export ports. It is worth mentioning the advance of soybean exports through the ports of the Northern and Northeastern regions, among which: Port of Itaqui, in Maranhão; Port of Vila do Conde, in Pará; Port of Salvador, in Bahia; Port of Manaus, in Amazonas, and Port of Santarém, in Pará.

One advance is the recent completion of the paving of the BR-163 road, which allows the flow of grain production from the main producing regions of the country, located in the Midwestern region, especially in the state of Mato Grosso, via Miritituba (district of the municipality of Itaituba, PA) and Santarém, with lower costs, transport time and risk of accidents.

Other important advances lie in rail transport, especially with regard to the North-South and East-West railroads. The completion of segments in Matopiba in recent years and the concession policy adopted by the federal government will make it possible to reduce transport costs and increase efficiency in the flow of grains.

Among the advances in logistics projected for the coming years, which will have an impact on agribusiness logistics, the following stand out: 1) rock removal of Pedral do Lourenço, in the state of Pará, which will make the Araguaia-Tocantins Waterway navigable; 2) the construction of the bridge between Porto Murtinho (Mato Grosso do Sul) and Carmelo Peralta (Paraguay), essential for the Bi-oceanic Route, which focuses on the feasibility of a road corridor to the Pacific Ocean. The first project will boost agriculture in the states located further to the Center and Northern regions of Brazil, while the second project will encourage the advancement of agricultural production in the central region of the country, especially in Mato Grosso do Sul.

Primary production value

In the current decade, it is observed that soybean generated a higher remuneration than that generated by other first crops, in most of the years, which was the reason for the expansion of its area. It is emphasized that technological development has been vital, as it allowed the introduction of the crop in regions with edaphoclimatic conditions different from those observed in traditional farming areas. In this scenario, the Gross Production Value (VBP) of soybean in Brazil, estimated in June by MAPA, is above US$ 33.28 billion, 19.8% higher than the VBP achieved in 2019 (US$ 27.58 billion). Soybean, as the main Brazilian export product, had a turnover of 26.328 billion dollars, 6.727 dollars less than that observed in 2018, reflecting the decrease in imports by China, because of the swine flu.

Dynamic and modern production chain

Due to the advancement of the crop, large global companies have established their factories or business centers in Brazil, such as machinery, fertilizers and pesticides upstream, and soybean commercialization and industrialization downstream. The development of the soybean production chain stimulated other production chains, such as maize, cotton, cowpea and sorghum, crops that expanded their second crop area, in succession to soybeans. Animal production chains were also encouraged, such as poultry, swine, cattle and fish, for which oilseed is an essential raw material in their diet. Soybean has also been important for the sustainability of other crops, being adopted in the renewal of sugarcane fields and rotation with regional species, such as rice in Rio Grande do Sul and grass (for seed) in northern Minas Gerais.

Adding value to meat and other foods

There are more than two thousand uses of soybean. We hardly spend a day without having contact with a product that contains soybean. Currently, it is possible to find in a supermarket close to 250 food products that contain soybean. In this context, every citizen consumes soybean daily, whether in the form of food or other products that carry the grain. This creates a high demand for soybean, which is largely produced in Brazil. In this context, society's habits dictated the direction of soybean research, guiding agricultural research in parameters associated with the crop (e.g., protein content), as well as the development of soybean-based products (e.g., food, tires, paints, cosmetics).

Leadership in exports

From the 2000s onwards, year by year, soybean has been consolidating itself as the main Brazilian export production chain, taking off from the other production chains (meat, sugar and ethanol, coffee and forestry). The following records of surplus in the Brazilian trade balance have, in the exchange revenue of soybeans, the bastion that makes it possible to offset imports from other sectors and the deficit in the balance of services. In 2019, soybean was responsible for 14% of Brazilian exports and 43% of agribusiness exports, in addition to its trade surplus (32.5 billion dollars) accounting for more than 60% of the Brazilian trade balance, which reached more than 48 billion dollars, according to Comex Stat data, of July 2020.

Rural middle class and family farming

According to the Census of Agriculture, more than 60% of soybean-producing establishments have up to 50 ha and more than 90% have up to 500 ha. In other words, Brazilian soybean production is mostly carried out by small and medium-scale family producers and, according to panels carried out by Embrapa, the crop has been essential for the formation and maintenance of a rural middle class, boosting the socioeconomic development of Brazilian agriculture.

Soybean has contributed to the quality of life of producing municipalities, which can be found in indicators such as the Firjan Municipal Development Index (IFDM). As an example, Lucas do Rio Verde, MT, and Luís Eduardo Magalhães, BA, municipalities whose economy is driven by soybean, are those that achieved the highest IFDM in their respective states. Furthermore, in Mato Grosso, nine of the ten municipalities with the highest IFDM are important soybean producers, some of which have processing industries.

The advancement of agribusiness has been essential for Brazil's socioeconomic development, but it has not been the proper acknowlegment. This evolution has led to the establishment of production hubs (agricultural municipalities), service hubs (municipalities with service provider organizations) and agribusiness hubs (municipalities with agribusinesses), which provide not only advances in the quality of life in agricultural regions, but also the reduction of the social isolation of many places, either by the recomposition of its population or by the greater movement of people.

Automation of management processes and methods

The machines and equipment used in soybean production are increasingly efficient. This factor, together with the training of producers and their families, has provided an increase in productive efficiency and the gradual insertion of women in agriculture, in mechanized operations and, especially, in the management of the agricultural business. With the advancement of Agriculture 4.0, it is expected that universities and young people will have greater participation in Brazilian agriculture, which will bring positive impacts both for productive efficiency and for the image of agribusiness.

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Chapter 8

Beef cattle

Optimization of land use and adoption of sustainable intensification

Photo: punkfurunfo (Pixabay)

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Sustainable intensification in Brazilian beef cattle farming aims to optimize land use, making the areas used reach, from an economic-environmental point of view, their ideal production point, exerting the effect known as land-saving. Therefore, there are several technologies used in beef production that have been proven to lead to a substantial increase in several zootechnical indices, which are the best indicators for improving efficiency of meat production systems. It is worth noting that, regardless of the specific type of production system and the technologies adopted, their use and increase is always positive in terms of the land-saving effect and, consequently, of increasing the sustainability of production systems, which leads us to believe that Brazil can even double its total beef production in the coming decades without the technical need to clear new areas.

Land use and sustainable intensification

The evolution of the agricultural sector inevitably leads to changes in land use, wherever in the world. The quantity, quality and speed of this change, however, are variable. Furthermore, these factors can have positive or negative consequences, depending on the socioeconomic situation in the region and its orientation towards sustainable development. Currently, developing countries, such as Brazil, seek greater sustainability in the agricultural sector, and one of the paths for this is orderly and, in a certain way, verticalized growth, for example, intensifying the activities already developed in areas in use to minimize the need to clear new areas. In industrialized countries, on the contrary, intensification is linked to the often excessive use of industrialized inputs that generate negative externalities, mainly on the environment.

Specifically in Brazilian cattle farming, sustainable intensification aims to optimize land use, making the areas used reach, from an economic-environmental point of view, their ideal production point. This does not necessarily mean greater use of inputs, but rather a better combination of biotic and abiotic factors, with better use of technologies that favor productivity, both for the soil and for the animals. It also does not imply loss of animal welfare, or any damage to biodiversity.

The evolution of beef cattle in Brazil: an overview

Cattle farming is the only activity present in all Brazilian municipalities, and in more than half of the municipalities in some states, this is the main economic activity. Even though it occupies a large part of the country, there is still room for its growth, without necessarily advancing into forested areas, which is more difficult to be done in other countries in Latin America and also in Australia, Africa and Asia. In some cases, as in the systems in integration of the silvopastoral (livestock-forest)

Photo: Breno Lobato

and agroforestry (crop-livestock-forest) types, there is even the restoration of the landscape with the introduction of native or exotic trees, with recognized environmental, economic and social advantages, including ecosystem services such as carbon sequestration and animal welfare, among others.

In addition, since 2004, Brazil has stood out as the world's largest player in the meat sector, exporting more than 1 million tons beef. This primacy was maintained in the following decade, reaching its peak in 2019, with 1.86 million tons[1] exported, responsible for about 20% of the sales of slaughterhouses. Furthermore, in the last 10 years, from 2009 to 2019, the share of beef cattle in Brazil's total GDP increased from 7.8% to 8.5%, and in 2019, Brazil exported beef to 154 countries, 53 more countries than the previous year, according to ABIEC (2020).

From 2004 to 2019, the number of slaughtered cattle, according to the Brazilian Institute of Geography and Statistics (IBGE), increased by approximately 25%, from 25.94 million to 32.45 million[2], indicating an increase in offtake, considering that, in the same period, the Brazilian cattle herd presented a slight increase, of 4.5%, from 204.51 million to 213.68 million head (ABIEC, 2020). As for the total produced weight of carcasses, from 2004 to 2019, there was an increase of 39%, from 5,906 million tons to 8,219 million tons[3], and the weight per carcass increased from 228 kg to 253 kg during the same period, indicating an improvement in the efficiency of meat production in the country.

It is necessary to consider that all this increase took place without it being necessary to increase the area of pastures. Official data, in the comprehensive period between the 2006 and 2017 Censuses of Agriculture, prove that the total area with pastures in Brazil was practically unchanged, from 160 million hectares to 159 million hectares. Since there was a relative increase in areas with planted pastures (+10%) to the detriment of areas

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[1] Available at: http://abiec.com.br/exportacoes.

[2] Available at: https://sidra.ibge.gov.br/tabela/1092.

[3] Available at: https://sidra.ibge.gov.br/tabela/1092.

with natural pastures (-18%) (IBGE, 2006, 2017), which indicates greater investment in technology, with the perspective that areas with natural pastures have been incorporated to higher levels of productivity.

Another indication of the improvement in the efficiency of beef production in Brazil can be observed from ABIEC data (ABIEC, 2020), in which the percentage of steers (except bulls) finished with more than 36 months, in the total of males, in the period from 2004 to 2019, decreased from 34.2% to 5.9%. This reinforces the increased use of technologies that accelerate the production cycle, favoring precocity and its benefits, such as better meat quality. The recovery of degraded pastures, use of systems in integration, feedlot finishing and grain feeding on, use of fertilizers on pastures, animal supplementation, use of adapted forages, use of heat-tolerant cattle breeds and use of good agricultural practices, among others, stand out.

The land-saving effect of Brazilian beef cattle

There are several technologies used in the production of beef, whose estimated impacts optimize land use, exerting the effect known as land-saving. To facilitate the description and understanding, these can be grouped taking into account the main requirements of the Brazilian productive systems, namely:

- Animal genetic improvement and reproductive biotechniques.
- Improvement, management and recovery of pastures.
- Grain feeding on pasture and feedlot finishing.
- Disease and parasitic control.
- Integrated production systems.

The constant use and improvement of these technologies has been proven to lead to a substantial increase in various zootechnical indices, which are in this case the best indicators of improving the efficiency of meat production systems, which ultimately culminate in the indicator – amount of meat produced per hectare per year with what level of impact. It is important to emphasize here that, since these are extensive systems generally below their productive potential, increasing the efficiency of meat production systems does not necessarily mean an increase in the environmental impact, quite the opposite, as in the case of degraded pastures, their recovery greatly increases their productivity and takes them from a situation of sources of greenhouse gases to an excellent sink, providing carbon fixation in the soil.

Therefore, the main indexes considered here were: pasture stocking rate, reduction in the slaughter age of cattle or their entry into reproduction, especially in the case of females, increase in fertility, increase in weight at weaning, reduction in mortality and increase in carcass weight of the slaughtered animal. For purposes of calculating the area of land "saved" by the productivity improvement provided by each technology, the analysis was based on productivity indices from 3 or 4 decades ago, when the expansion of the Brazilian agricultural frontier actually began, as summarized in Table 1.

At the end of this chapter, the case of Mato Grosso do Sul is briefly presented, considered the pioneer state in the past in relation to the expansion of the agricultural frontier, and in the present in the adoption of land-saving technologies. The analysis of land use changes, considering the entire territory of the state, together with the beef production data, prove that the intensification of beef cattle farming allows for the availability of space for other agricultural activities and even the increase of areas of natural preservation, without prejudice to meat production.

Estimates of the land-saving effect of technologies used in Brazilian beef cattle

Cattle genetic improvement and reproductive biotechniques

The Brazilian cattle herd went through recognized genetic evolution due to the advance of techniques and genetic improvement programs. Their pioneer was the Melhoramento Genético de Bovinos de Corte (Beef Cattle Genetic Improvement Program – GENEPLUS), led by Embrapa, the Associação Nacional de Criadores e Pesquisadores (National Association of Breeders and Researchers – ANCP) and the Associação Brasileira dos Criadores de Zebu (Brazilian Association of Zebu Breeders – ABCZ) (Ferraz; Felício, 2010). More recently, programs have begun to employ even more advanced genetic evaluation techniques using genomic data associated with phenotypes. In addition, the increase in the use of industrial crossbreeding from Zebu breeders (Nellore and their crossings) and bulls of taurine and compound breeds should be highlighted. The impact of genetic improvement can be measured, for example, by the increase in carcass weight at slaughter, by the reduction in age at slaughter and at first reproduction, and by the increase in fertility. In an assessment based on weight gains at weaning, Rosa et al. (2016) estimated that the use of breeder bulls can increase the weaning weight of commercial farms by 15.26 kg, which may mean an increase of more than 10% in this phase of the production cycle, in

Table 1. Brazilian beef cattle productivity indexes at the beginning of the expansion of the agricultural frontier.

Indicator	Unit	Amount	Reference year	Reference
Productivity	kg of carcass equivalent per hectare per year	11.97	1970	Martha Junior et al. (2012)
Male carcass weight	kg	225.00	1983	Thiago and Costa (1983)

which the animal has not completed 1 year yet. In 1970, there were no cattle breeding programs in Brazil. Considering that the production of breeder bulls is in the order of 200,000 and that these are mated with 6 million cows per year, with an average weaning rate of 65%, the production of 3.9 million improved calves is expected, with the additional production of 59.5 thousand tons of live weight already at weaning, which is equivalent to 29,800 tons of carcass. This amount of carcass provided by genetic improvement to increase live weight production would require the equivalent of 2.49 million additional hectares per year, if the productivity obtained in 1970, adopted as a reference for this analysis, is taken into account.

In the cattle breeding context, artificial insemination (AI) is an essential technique for genetic improvement of the herd, either by selection or by industrial crossing. The increase of this technology with the use of fixed-time artificial insemination facilitated the management of production systems, increasing its use, and being of great influence for its expansion both in the recent past and in the future. The impact of AI, in addition to improving the genetic quality and uniformity of animal lots, with a direct impact on management and marketing, has a great influence on improving the performance of progenies resulting from its use, in addition to possible benefits on fertility indices. According to ASBIA (2020), 16% of beef cows are currently inseminated in Brazil, increasing 6% since 2012. According to Baruselli (2020), the increase rate in the employment of artificial insemination is high, going from 3.4 million in 2002 to 9.7 million inseminated cows. It is also estimated that artificial insemination can currently be used in 10.2 million cows, increasing calf production by 8%, equivalent to 816,000 calves per year (Baruselli et al., 2019). It is also estimated that the carcass weight at slaughter is increased by 15 kg in calves from artificial insemination, for an additional production of 12.2 thousand tons of carcass. Considering productivity in the 1970s, reported by Martha Junior et al. (2012), artificial insemination proved to be able to save 1.02 million hectares per year.

It should be highlighted, once again, that the technologies that improve the final indices of cattle systems have a close interaction with each other and an evident synergistic effect, however difficult to dissociate from each other. In this case, for example, it is difficult to estimate the land-saving effect of genetic improvement of herds alone. All index improvements that lead to the land-saving effect, from pasture improvements to nutritional technologies, for example, rely on the genetic improvement of herds. The high productivity in feedlots, which leads to a greater production of carcass per hectare and a reduction in the need for farmed areas, is also a result of the improvement in the genetic potential for weight gain of the animals and not just the greater offer of better feeding.

Improvement, management and recovery of pastures

From the 1970s, with the development of forage cultivars that are more productive and resistant to pests and diseases for pastures, the farms increased their stocking capacity, increasing the herd in relation to the same area, or reducing the area for the same herd. In addition, significant gains were made in animal productivity. An account of how the indices were transformed at the time of the implementation of sown pastures in Brazil was given by Lima et al. (1979). In a research carried out at Embrapa Beef Cattle, evaluating the effect of cultivated pasture on the age at first reproduction of Zebu females, the authors reported that the use of sown pasture alone made it possible to advance the age at first calving by 1 year.

Using data from IBGE, Martha Junior et al. (2012) reported that the stocking rate went from 0.51 head per hectare in 1970 to 1.08 head per hectare in 2006. ABIEC (2020) reports a stocking rate, in 2019, of 1.31 head per hectare, which is equivalent to a stocking rate 257% higher than that of 50 years ago. It is noteworthy that the increases obtained in productivity in recent decades were also the result of improved techniques for managing pastures and soil.

Foto: Gabriel Rezende Faria

Considering a herd of 213.70 million head and the stocking rate that existed in 1970, the area needed today for the herd in such a scenario would be 418.98 million hectares, whereas, in reality, today cattle farming occupies only 162.53 million hectares, i.e., 256.5 million hectares less.

In this context, discounting the number of animals intensively finished in feedlot and pasture and considering the following calculations, intensive finishing in feedlot and pasture together can have a land-saving effect of 85.7 million hectares. Therewith, the final land-saving effect of the use of sown pastures in Brazil could reach 180 million hectares.

Dry feed supplementation on pasture and feedlot finishing

With genetic improvement, the development of more productive forage cultivars and the wide dissemination of pastures cultivated in Brazil, cattle farming has definitely been supported by pasture production systems, with an estimate that more than 95% of the beef produced in this type of system, considering the cycle from birth to slaughter. However, the evolution in the use of pastures also went through the solution of some nutritional problems through the development and diffusion of the use of practices such as mineral supplementation, protein and protein-energy supplementation, intensive finishing in pasture and feedlots. All of these were innovative techniques for their time, since they were able to compensate nutritional deficiencies in the plants themselves and in Brazilian soils, in addition to the well-known seasonality on forage production, i.e., the reduction in growth and loss of nutritional quality of pastures during the dry season.

Regarding mineral supplementation, having its advent in the 1970s, studies have shown that its adoption leads to a 36% increase in the weaning rate, a 30 kg increase in weaning weight and a 38.9 kg increase in weight gain per year (McDowell, 1999). Taking into account that the last indicator can be considered as the additional weight to the slaughter of young animals, that the number of animals slaughtered considered young in 2019 was 5.2 million head[4] and that only 50% of the rearing and fattening herd receive mineral supplementation, the additional production in carcass can be equivalent to 50.5 thousand tons of carcass. This number is equivalent to saving 4.22 million hectares of land per year with this simple technique alone, considering as always the productivity reference of the 1970s. Considering that the increase in the weaning rate, cited by McDowell (1999), is 22%, that mineral supplementation occurs in 50% of the herd (conservative number) and that the slaughter of calves in 2019 was of 1.57 million, the additional demand for cows needed for the production of calves to supply the referred number of slaughters would be 1.47 million.

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[4] Available at: https://sidra.ibge.gov.br/tabela/1092.

Considering the stocking of 1.06 animal units per hectare (ABIEC, 2020), mineral supplementation may be saving another 1.39 million hectares, in a total of 5.61 million hectares per year.

In order to reduce the effects of forage seasonality, two practices have increased their adoption: feedlot finishing and intensive finishing in pasture. According to Abiec (2020), 6.09 million animals slaughtered in 2019 were fattened in feedyards. This represents an evolution of more than 4 million head when compared to 2001 (2.06 million), the oldest period covered by that publication. Unfortunately, it is not possible to pinpoint the number of animals fed in the 1970s, but the number is believed to be below 500,000 animals per year. On the other hand, intensive finishing on pasture is relatively recent in Brazil and there are no statistics on its use. However, due to the ease of its adoption, it is reasonable to say that the number of animals finished using this strategy is at least 50% of that referring to feedlots, i.e., 3 million head.

Feeding beef cattle in Brazil has an interesting peculiarity when compared to other countries. In Brazilian systems, animals are put on feed on average only for the last 90 days prior to slaughter, with weight gain over the period of approximately 1.4 kg per animal per day (Oliveira; Millen, 2014), with approximately 65% of weight gain takes place in carcass, in a total of 81.9 kg of carcass produced per animal. In addition to the aspects of animal welfare and low use of external industrialized inputs, since feedlots are normally carried out in the dry period of the year, their productivity must be compared with the expected weight gain of animals exclusively on pasture receiving mineral supplement. In this scenario, a gain of 0.10 kg day^{-1} is expected and the productivity in 90 days would be 5.85 kg of carcass.

In terms of the land-saving effect of feeding, considering a stocking rate of approximately 500 animals per hectare and daily consumption of 25 kg of a diet composed of forage, maize and soybean, it is estimated that the area needed for the fed fattening phase is 0.17 hectare per head – based on grain yield described by Acompanhamento da Safra Brasileira [de] Grãos (2019). As for fattening on pasture with mineral supplementation, the area requirement would be 0.76 ha per head based on the estimated average stocking rate of 1.31 head per hectare (ABIEC, 2020). Considering that 6.09 million head fed would produce 498.8 thousand tons of carcass with a demand of 1.04 million hectares, the same herd in the pasture scenario would require 65.10 million hectares to

Foto: Vanderley Porfírio da Silva

produce the same amount of carcass. Thus, feedlot finishing is capable of exerting a land-saving effect of 64 million hectares per year.

As for intensive finishing on pasture, as well as feedlots, it allows to reduce the slaughter age by up to 6 months, or even to increase carcass production in the same finishing period. It is the supply of concentrated feed at levels between 1.5% and 2.0% of live body weight, in stockings of 4 to 10 animals per hectare. In a conservative approach, considering a stocking of 4 animals per hectare and daily consumption of 8 kg of feed composed of maize and soybean, it is estimated that the area required for the fattening cycle in intensive finishing on pasture is 0.39 hectares per head – based on grain yield described by Acompanhamento da Safra Brasileira [de] Grãos (2019). As for fattening on pasture with mineral supplementation, the area requirement would be 0.76 hectare per head based on the estimated average stocking rate of 1.31 head per hectare (ABIEC, 2020). Considering that 3 million head in intensive finishing on pasture would produce 175,500 tons of carcass with a demand of 1.16 million hectares, the same herd in the pasture scenario with minerals would require 22.9 million hectares to produce the same amount of carcass. Thus, intensive finishing on pasture is capable of exerting a land-saving effect of 21.7 million hectares per year.

Disease and parasitic control

In addition to the aspects of genetic improvement, reproduction and

Photo: Luiz Antonio Dias Leal (Pixabay)

nutrition, the health of the herd has a very significant influence on the improvement of zootechnical indices that culminate in the land-saving effect. In addition to avoiding low performance losses caused by diseases and parasites, it is important to note that more productive herds are also more susceptible to these factors, somewhat proportionally increasing the importance of this aspect as animal performance increases.

The advance in the control of bovine diseases is, without a doubt, one of the great achievements for the increase in the productivity of Brazilian beef, as well as for the expansion of the internal and external consumer market. Although not all advances are easily quantifiable in terms of impact on the land use issue, some have clear benefits on animal performance, allowing for analysis in this approach. Strategic helminth control is an example of a technology developed in the 1970s and widely used today. Defining the frequency and the best period of anthelmintic use, the control known as 5-7-9 (numbers referring to the months of anthelmintic application in Central Brazil) (Bianchin et al., 1995) is able to increase individual weight gain up to 42 kg year^{-1} in growing and fattening cattle up to 24 months of age. To estimate the land-saving effect of this technology, the slaughter in 2019 of 5.2 million steers and heifers, young animals for which the use of strategic helminth control is recommended, was considered, an additional gain of 20 kg in weight of carcass and a conservative estimate of adoption of 50% of the technology. In this calculation, the strategic control of helminths would provide an additional carcass production of 52,000 tons. Considering the productivity per hectare in the 1970s described by Martha Junior et al. (2012), the land-saving effect would then be equivalent to 4.3 million hectares.

The Programa Nacional de Controle de Erradicação da Brucelose e da Tuberculose Animal (National Program for the Control and Eradication of Brucellosis and Animal Tuberculosis – PNCEBT) was established in 2001 by the Ministry of Agriculture, Livestock and Food Supply (MAPA) to reduce the prevalence of those diseases. It is estimated that the implementation of the brucellosis vaccination program led to a reduction in the prevalence of infected herds in Minas Gerais, Rondônia, Mato Grosso and Mato Grosso do Sul by 43% on average over a period of 10 years (Ferreira Neto et al., 2016). Based on estimates of economic losses made by Santos et al. (2013) and considering only the four states mentioned, it is estimated that losses of 24,600 tons of carcass were prevented, which, compared to the productivity of the 1970s, would be equivalent to a land-saving effect of 2.06 million acre. Obviously, considering that the diseases in question are also public health issues, there is an immense impact of the PNCEBT that cannot be measured by the land-saving effect approach.

Photo: Breno Lobato

Integrated production systems

In 2010, Brazil was a pioneer in proposing the Plano de Agricultura de Baixa Emissão de Carbono (Low Carbon Emission Agriculture Plan – ABC Plan). In its second phase (2020–2030), it has stimulated the use of improved technologies related to beef cattle, such as pasture recovery and integrated systems. In the 2016/2017, 2017/2018 and 2018/2019 seasons, the total resources contracted by ABC Plan were US$ 542 million, US$ 453 million and US$ 429 million, respectively, of which 61%, 48% and 38% of these resources directed to pasture recovery; and 7%, 6% and 6% with integration systems, respectively (Observatório ABC, 2018, 2019).

Since then, the use of Integrated Crop-Livestock-Forest (ICLF) systems for beef, grain and wood production has become a reality in Brazil. Among its advantages are sustainable intensification of land use, diversification of production, soil conservation, better use of natural resources and inputs, reduction of pressure to clear new areas (land-saving effect), greater animal welfare, carbon sequestration, mitigation of greenhouse gases emissions, among others.

With the adoption of integrated systems in their different combinations, the farmer obtains an additional product in the same area of land previously occupied with traditional systems, including wood, grain and beef in the same area. Depending on the configuration of these systems, which can vary greatly, it is estimated that the land-saving effect is 30% to 50% in areas occupied by integrated systems, reaching figures close to 75% depending on the productive potential of the area and the level of intensification adopted. Considering a survey carried out by the ILPF Network Association (ILPF..., 2016), an area of 11.5 million hectares is estimated with the various types of integration systems, 83% of which with integrated crop-livestock system (ICLS) or agropastoral systems, 9% with integrated crop-livestock-forest system (ICLFS) or agroforestry systems, and 7% with integrated livestock-forest system (ILFS) or silvopastoral systems, with 1%

with integrated crop-forest system (ICFS) or silviagricultural systems, which do not involve livestock. Thus, on a more conservative estimate, the integrated systems would be capable of imposing a land-saving effect in the order of 3.45 million hectares.

Case study: improving land use efficiency in the state of Mato Grosso do Sul

The Northern-Central region of Brazil is currently where the biggest changes in land use in Brazil are taking place. In this context, the state of Mato Grosso do Sul can be considered a good "thermometer" of how these changes tend to occur. Extensive beef cattle ranching is one of the main economic activities in the state. Due especially to its proximity to the Southeastern and Southern regions, where the largest consumer centers and export hubs are located, other agribusiness activities have expanded in Mato Grosso do Sul, especially by influencing land prices and consequently leading to changes in its use and occupation.

Traditional activities in the state have shown signs of adjusting to the different aptitudes of each region, according to available resources, especially related to soils and climate. Naturally, the beef cattle chain as a whole and the farms, individually, are led to promote the respective changes in their production systems in order to remain competitive.

In order to analyze in more detail this dynamic in land use that is perceived in Mato Grosso do Sul and which may in the future be repeated in other regions of the country and even in other parts of the globe with similar conditions, a study was carried out considering the geographic micro-regions of the state, with the changes in land use that occurred in them between 2010 and 2014. Data from the Sistema de Informações Geográficas do Agronegócio de Mato Grosso do Sul (Mato Grosso do Sul Agribusiness Geographic Information System – SIGA/MS), organized by the Associação do Produtores de Soja e Milho de Mato Grosso do Sul (Mato Grosso do Sul Soybean and Maize Producers Association – APROSOJA/MS) and the Famasul System were used.

Figure 1, which aggregates the main agricultural activities in the region, shows that the growth in the production of grains, sugarcane and commercial forests, essentially eucalyptus, occurred over pasture areas.

With an increase of almost 1 million hectares, the total area under farming increased from 2.77 million to 3.74 million hectares between 2010 and 2014. The pasture area, which covered 61% of the state's total area in 2010, dropped from 21.82 million to 20.03 million hectares in the period. The forestry sector grew by 106%. At the same time, there is another very interesting aspect from an environmental point of view: the total area of remnants of native vegetation

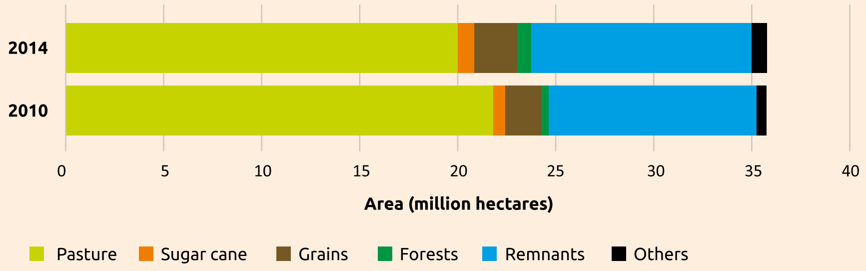

Figure 1. Changes in the main land uses in Mato Grosso do Sul state, between 2010 and 2014.

Source: Bungenstab et al. (2014).

has increased by more than half a million hectares.

The advance of crops over pasture areas led to a reduction in the total cattle herd in Mato Grosso do Sul. However, this change occurred in varying degrees depending on the region of the state and its agricultural suitability. When analyzing in detail the herd data and slaughter volumes, it was observed that, while there was a constant reduction in the number of cattle, the number of animals sent to slaughter increased in the last 4 years. In numbers, while the state herd had a reduction of more than 1 million head, the number of animals slaughtered had an increase of more than 60,000 head. These figures show the trend towards an increase in the productive efficiency of the beef cattle herd in the state, especially related to the reduction in the slaughter age of the animals. This occurs naturally due to the need to optimize land use.

The detailed analysis of the data also allows us to verify that the forestry sector, in special, has expanded in the eastern region of the state, with less fertile soils, traditionally occupied by cattle ranching. The herd in this region, consequently, also suffered reductions, but these were not as drastic as in regions with more fertile soils. And most importantly, these herd reductions did not occur in the same ratio as the reduction in pasture areas, considering the average animal stocking per hectare. This demonstrates that the farmer is willing to improve its production system to continue in the activity.

This is a very important aspect of the analysis carried out, since there is a great potential for expansion of integrated systems, especially in livestock-forestry, but also in crop-livestock-forest.

The integrated crop-livestock systems have, in a way, the ease of producing two simple commercialized commodities, in this case, beef and grains. On the other hand, systems that incorporate the forest component require a lot of prior attention to the aspect of selling the forest product, especially for issues of harvesting and transport logistics to the processing unit.

Conditions, therefore, are more favorable for the development of integrated systems in those areas where there is already a regional infrastructure for the forest sector. This would facilitate both the implementation of these systems, as in the case of outsourcing the planting of trees, as it would ensure the ideal destination and satisfactory remuneration of its products.

Technologies are being developed and made available specifically for integrated production systems. Likewise, there is a government incentive with specific credit lines for this. Therefore, in regions with characteristics similar to those of Mato Grosso do Sul, dialogue and partnership between cattle farmers and grain producers, but especially with the forestry sector, can bring excellent results for all parties involved. In this way, it will not only be possible to promote regional development, but actually implement agro-industrial production systems based on sustainable intensification.

Perspectives

Regardless of the specific type of production system and the technologies adopted, their use and increase is always positive in terms of land-saving and, consequently, increasing the sustainability of the systems. The analyzes carried out in this document do not mention all the technologies capable of being evaluated, nor are they intended to be fully accurate, since there is a known interface and interaction among technologies, which is difficult to delimit. In any case, being aware of the progress already achieved, as evidenced by the figures presented herein, and with the range of technologies available and under development, we are convinced that it is possible to continue increasing the productivity of Brazilian livestock systems, perhaps even doubling its total production in the coming decades without the technical need to clear new areas to reach these figures.

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Chapter 9

Technological and sustainable advances in the Brazilian broiler and swine chains


Photo: Lucas Scherer

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In recent decades, the continuous technological advances introduced by the broiler and swine production chains in recent decades have avoided the demand for an additional 2.55 million hectares for maize and soybean production in Brazil. This area is equivalent to the territories of Cyprus and the USA state of Connecticut combined. It also means 4.6% of the 55.4 million hectares that maize and soybeans occupy in the 2020/2021 season in Brazil (Conab, 2021). The saved area estimate for broiler and swine production relates to the gains in feed conversion achieved over time.

Contextualization

The broiler and swine production chains have been exponents of important transformations that have taken Brazil to a prominent position in the world as a food producer (Chaddad, 2016). In addition to contributing significantly to improve life quality in Brazil, providing quality animal protein at an affordable price, the two chains contributed to issues of interest such as soil preservation (ABPA..., 2020; Embrapa Suínos e Aves, 2021). In 2020, Brazil was the world's third largest producer of chicken meat, with 14.2 million tons, and as the largest exporter, with 4.2 million tons. In pork, the country ranks fourth as producer and exporter, with 4.2 million and 1.01 million tons, respectively (Brasil, 2021).

The social effects of the broiler and swine production chains are also remarkable. Both activities generate about 4.2 million direct and indirect jobs (ABPA..., 2020). Moreover, through the integrated and independent production systems, the activities involve more than 100,000 families in primary production (Guimarães et al., 2017). There are countless small municipalities in the country whose economic activity depends on the full functioning of meat processing plants installed in each region (Mapeamento..., 2016).

The social benefits of poultry and swine farming are not limited to the jobs and income generated in municipalities where primary production and agro-industrialization take place (Santos Filho, 2012; Santos Filho et al., 2015). Both are drivers of development for entire regions or states, impacting services, transport and trade sectors. In addition, the favorable climate, investments in renewable energy sources and the quality of production facilities allow Brazil to produce chicken with a carbon dioxide (CO_2) emission level 45% lower than those produced in the United Kingdom and 50% lower than those produced in France (United Kingdom, 2021). Furthermore, almost all poultry and pork production happens outside the Amazon biome – the Southern and Southeastern regions account for more than 80% of production (Produção..., 2014).

Continued technological progress in poultry and swine and the economy in the use of maize and soybean cultivation areas

The continuous investment in technological development is one of the pillars that explain why Brazilian poultry and swine production ranked among the best in the world (Souza et al., 2011). From the 1970s onwards, companies, producers, research institutions such as Embrapa and government agencies worked in synergy to develop local solutions or adapt new technologies generated in other parts of the world to Brazilian reality (Talamini et al., 2014). The result of this joint effort is that Brazil has one of the most efficient poultry and swine production in the world (Mapeamento..., 2016).

One indicator that best expresses the technological development achieved by the two activities is feed conversion rate (Fischer et al., 2019). In short, feed conversion is the amount of feed an animal needs to consume for every kilogram of weight it gains. Food conversion is revealing because it, as it progresses, reflects technological gains achieved in different areas. In other words, feed conversion relates straightly to the progress made over the years in various technical areas, such as genetic improvement, nutrition, animal health, management and ambience.

Feed conversion rate is also the key to understanding how poultry and pig farming relate to land use. Chickens and swine consume large amounts of maize and soybean meal in their diets, absorbing a large part of the Brazilian production of these cereals. This means that the better the relationship between feed consumed and the animals' weight gain, the less pressure these activities exert on expanding areas for the production of maize and soybeans.

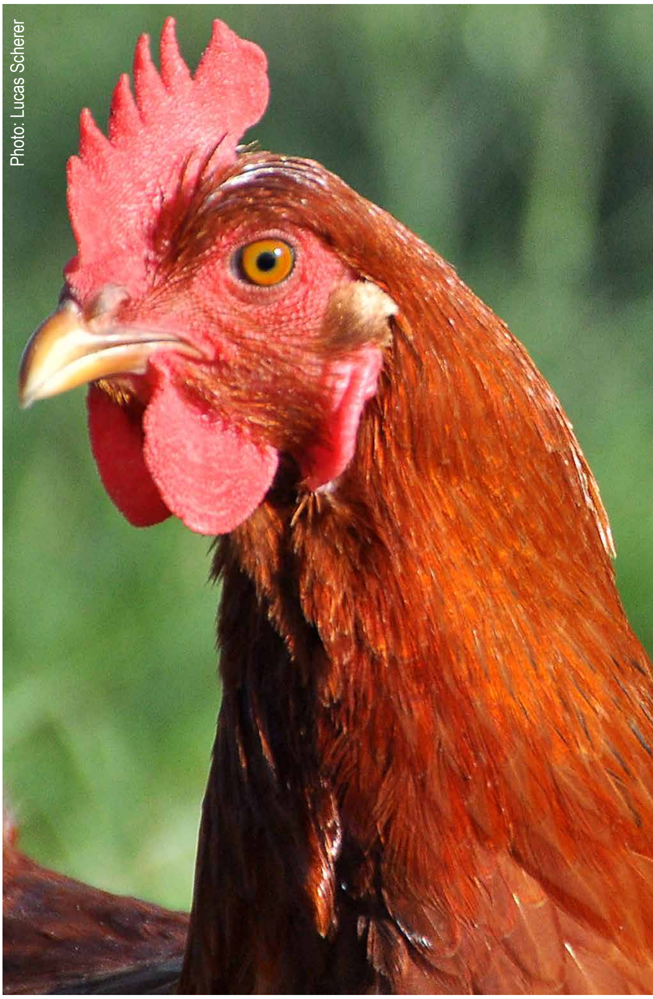


Photo: Lucas Scherer

About 1.55 million hectares saved in poultry industry

Table 1 compares the average feed conversion achieved by the commercial production of Brazilian broiler chicken in the years 1975 and 2020. In 1975, it was needed 2.1 kg of feed to gain 1 kg of live weight while in 2020, that same kilo of weight required 1.7 kg of feed. Considering the country's current productivity of maize and soybean, if technological development had not provided broilers with greater capacity to convert feed into weight gain, this industry would require an additional 1,551,056.40 ha of land to deliver the same 16.4 million tons of live weight produced in 2020. This area is equivalent to incorporating three times the size of the Brazilian Federal District into maize and soybean cultivation, if the poultry industry had not advanced its technological level.

Savings of more than 1 million hectares in swine farming

Table 2 compares the average feed conversion ratio of Brazilian commercial swine production in 1975 and 2020. In 1975, the swine consumed an average of 3.5 kg of feed to gain 1 kilo of live

Table 1. Estimated savings in the area of maize and soybean farmed due to improved feed conversion in the poultry industry.

Item	1975	2020
Production of live weight chickens (1,000 t)	679.8	16,452.1
World production share (%)	2.7	14.1
Export live weight (1,000 t)	4.2	4,843.1
World export share (%)	0.5	35.0
Food conversion (kg)	2.1	1.7
Final chicken weight (kg)	1.75	2.7
Feed consumed (1,000 t)	1,427.5	27,979.1
Feed savings (1,000 t)		6,581.2
Maize consumption (1,000 t)	999.2	19,579.1
Maize savings (1,000 t)		4,606.8
Productivity 2019/2020 (kg ha^{-1})		5,529.0
Maize: hectares saved		**833,212.8**
Soybean consumption (1,000 t)	535.3	10,488.8
Soybean savings (1,000 t)		2,467.9
Productivity 2019/2020 (kg ha^{-1})		3,438.0
Soybeans: hectares saved		**717,843.6**

Source: Patrício (2011), Brasil (2021), Conab (2021) and FAO (2021).

The **technological progress** poultry industry avoids the use of...

1.55

million hectares in Brazil

This area is equivalent to the territory of the USA state of **Connecticut**.

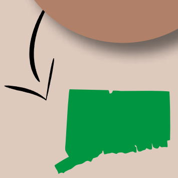


Table 2. Estimated savings in the area of maize and soybean farming due to improved feed conversion in swine farming.

Item	1975	2020
Swine production live weight (1,000 t)	972.8	5,373.8
World production share (%)	2.7	4.1
Export live weight (1,000 t)	50.0	1,021.0
World export share (%)	0.5	11.1
Food conversion (kg)	3.5	2.6
Swine final weight (kg)	100.0	120.0
Feed consumed (1,000 t)	3,404.8	13,971.9
Feed savings (1,000 t)		4,836.4
Maize consumption (1,000 t)	2,553.6	10,478.9
Maize savings (1,000 t)		3,627.3
Productivity 2019/2020 (kg ha^{-1})		5,529.0
Maize: hectares saved		**656,055.6**
Soybean consumption (1,000 t)	851.2	3,493.0
Soybean savings (1,000 t)		1,209.1
Productivity 2019/2020 (kg ha^{-1})		3,438.0
Soybeans: hectares saved		**351,690.1**

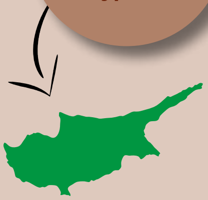
Source: Barbosa et al. (1988), Brasil (2021), Conab (2021) and FAO (2021).

The **technological progress** swine farming avoids the use of...

1

milion hectares in Brasil

This area is equivalent to the territory of **Cyprus**.



weight, while in 2020 this consumption was 2.6 kg of feed. Considering the current productivity of maize and soybeans in Brazil, if the technology did not provide the swine with greater capacity to transform feed into live weight, the activity would require an additional 1,007,745.70 ha of land to produce the 5.3 million tons of swine in 2020. This saving corresponds to a farming area equivalent twice the size of the Brazilian Federal District.

Photo: Griska Niewiadomski (Pixabay)

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AGRICULTURE, LIVESTOCK
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PÁTRIA AMADA
BRASIL
BRAZILIAN GOVERNMENT

ISBN 978-65-87380-43-8
9 786587 380438
CGPE 017028