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Farming Production in Brazil: Innovation and Land-Sparing Effect

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Abstract**—**Innovation and technology can be determinant factors to ensure agricultural and sustainable growth, as well as productivity gains. Technical change has contributed considerably to supply agricultural expansion in Brazil. This agricultural growth could be achieved by incorporating more land or capital. If capital is the main source of agricultural growth, it is possible to increase production per unit of land. The objective of this paper is to estimate: 1) total factor productivity (TFP), which is measured in terms of the rate of output per unit of input; and 2) the land-saving effect (LSE) that is the amount of land required in the case that yield rate is constant over time. According to this study, from 1990 to 2019, it appears that 87% of Brazilian agriculture product growth comes from the gains of productivity; the remaining 13% comes from input growth. In the same period, the total LSE was roughly 400 Mha, which corresponds to 47% of the national territory. These effects reflect the greater efficiency of using productive factors, whose technical change has allowed an increase in the agricultural production based on productivity gains.

Keywords**—**Agriculture, land-saving effect, livestock, productivity.

I. Introduction

THIS paper aims to discuss the following question: to what extent is technological gains over time and its sustainable impacts responsible for Brazilian agricultural and livestock production? As researchers that were part of this study, we understand that technical change and, consequently, productivity can influence the agricultural growth per unit of land, which also minimizes the pressure for natural resources. We are going to estimate, on one hand, TFP, or a rate of output per unit of input. On the other hand, the LSE is going to be measured, determining the amount of land required by a given yield in a period.

Agricultural production can increase from area expansion or higher productivity. Brazil is an example where new technologies allow area and yield growth simultaneously [1]. There is potential synergy between TFP growth and sustainability outcomes. Since the 1970s, Brazil has built a model of institutional induced innovation, which improved productivity in agriculture and livestock farming. Fishlow and Vieira Filho [2] considered this institutional change as the first wave of agricultural growth and sectoral modernization. Research centers coordinated by Embrapa developed science and technology applied to tropical conditions. These efforts motivated farming production into Cerrado biome. The absorption of new knowledge and innovation by agents has intensified the use of land and labor capacity, creating a dynamic process of continuous advances.

Since the early 1990s, Brazilian agriculture and livestock production has faced a second wave of growth. Based on the growth and deforestation debate, Brazil held in 1992 the conference on environment and development in Rio de Janeiro. Since then, the Brazilian economy has also played a central role in international issues of sustainable farming. In 2010, policies were addressed to climate change. Planned actions were established to increase pasture restoration (15 Mha), integration of agriculture-livestock-forestry (4 Mha), no tilled system (8 Mha), planted forests (3 Mha), nitrogen biological fixation (5.5 Mha), and waste treatment (millions of cubic meters). According to [3], Brazilian sustainable strategies contributed to reduce greenhouse gas emissions. This result has been associated with productivity growth and capacity to spare scarce resources.

Lapola et al. [4] and Tollefson [5] highlight the decoupling between agricultural expansion and deforestation in the last decades. Since the 2000s, annual deforestation trends began to decrease while there was an increase in agricultural production with cropland growth and cattle herd size intensification. There is no longer a direct correlation between food growth and deforestation trends. Brazil searches for a sustainable system that will help to raise agricultural production. The deforestation in all Brazilian biomes plunged to the lowest rate since monitoring began while cropland and cattle herds continued to increase[1].

Technology-driven investments and innovations to achieve

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[1] In June 2003, based on satellite images, the National Institute for Space Research (INPE) released data on the deforestation projection in the Brazilian Amazon from 2001 to 2002, indicating an accelerated growth of deforestation around 40% in relation to the previous period. The news about the increase in deforestation called for a careful evaluation of its causes, as a basis for planning a set of integrated public policies, to be implemented with the active participation of Brazilian society. The plan of action for prevention and control of deforestation in the Legal Amazon (PPCDAm, acronym in Portuguese) was created in 2004 [43].

sustainable farming are key factors that make the expansion of the production frontier possible, resulting in reduced production costs and increased profits [6]. Innovation increases productivity and, consequently, expands agricultural supply, which results in the fall in food prices. This process has a major impact on poverty reduction since food cost represents a considerable share of family income [7][2]. Agricultural growth is recognized as an important instrument for poverty reduction. According to [8], rural poverty reduction has been associated with growth in yields and in agricultural labor productivity.

In sum, productivity and land sparing are part of a cumulative process where food production (agriculture and livestock) expands, prices fall, poverty reduces, and sustainable and economic development advances. In order to evaluate this process, our study focuses on the period from 1990 to 2019, even though in some parts we highlight a wider timeline, including data and economic statistics since the 70s. Following this introduction, Section II describes the methodology used. Section III presents the main results. Finally, there are concluding remarks.

II. Methodology

This section presents the methodology used to estimate TFP and LSE.

A. Total Factor Productivity

TFP growth is understood to be an increase in output that cannot be explained by an increase in input. The residual factor, output growth rate minus input growth rate, or in other words TFP, can measure the productivity gains. According to [9], there are different ways of measuring TFP. One way is estimated by the Tornqvist index, as it has the flexibility to express changes in the economy [10]. The United States Department of Agriculture (USDA) also uses the Tornqvist index to track the evolution of TFP in American agriculture since 1985, approximately. Details on the concepts involved to calculate the index can be found in [11], [9] and [12].

One of the qualities of Tornqvist index[3] is that prices vary from year to year throughout the analyzed period. This price behavior allows the substitution between factors and output, and lets us to capture the change in quality that occurs over time. The representation of the Tornqvist index is as follows:

$$\ln\left({PTF_t}\big/{PTF_{(t-1)}}\right) = \frac{1}{2}\sum_{(i=1)}^{n}(S_{it} + S_{i(t-1)})\ln\left(\frac{Y_{it}}{Y_{i(t-1)}}\right) - \frac{1}{2}\sum_{(j=1)}^{m}\left(C_{jt} + C_{j(t-1)}\right)\ln\left(\frac{X_{jt}}{X_{j(t-1)}}\right) \quad (1)$$

In this expression Yi and Xj are, respectively, the quantities of outputs and inputs, and Si and Cj, respectively, are the shares of product i in the production value, and of inputs j in the total cost of inputs. Left side of the expression defines the variation in TFP between successive periods of time.

The first term in the second member of the expression is the sum of the logarithms of the ratio of the quantities of products in two successive periods of time, weighted by the share of each product in the total value of production. The second term is the logarithm of the ratio of quantity of inputs in two successive time periods, weighted by the share of each input in total cost [13]. To obtain the Tornqvist index from this expression, the following steps are necessary: i) after obtaining the result of that expression, the exponential of this result is calculated for each year; ii) the indexes are chained together [13], [14].

Output is a result of the aggregation of 31 products of temporary crops, permanent crops, with 24 products, animal production, 8 activities (milk, wool, chicken eggs, quail eggs, honey, wax and cocoon) and beef production, poultry and pork. Inputs are planted area of crops, pastures, agricultural machines (tractors, harvester, etc.), labor corresponds to workers in agricultural activities and livestock, pesticides, and fertilizers. It is necessary to have prices and quantities of each component of output and input. Into the Tornqvist index, output and each input participate by its share in total value of production or in the production cost.

B. Land-Saving Effect

In order to measure the LSE, this study computed the partial productivity of land (yields) and the partial productivity of livestock (which includes an indicator of stocking rate and carcass weight). In this context, as seen in (2), land productivity (Aa) in agriculture could be found by dividing production (P) by planted area (L):

$$A_a = \frac{P}{L} \quad (2)$$

In livestock production, according to (3), productivity (Al) is computed by multiplying livestock carcass weight (G) and stocking rate (S). The stocking rate is the quotient between the number of slaughtered animals (An) by the pasture area (L). The livestock carcass weight (G) is found by dividing production (P) by the number of slaughtered.

$$A_l = G.S \quad (3)$$

where S = An/L and G = P/An.

To compute the LSE, official statistics from the Agricultural Census and the Agricultural and Livestock Municipal Research [15]-[17] will be used. The LSE might reflect technical change over time. To let it clear, technical change might save some inputs and use other more. Alternatively, we could save land by using more of the other inputs, which would not necessarily reflect technical change. It might just be input substitution based on partial land productivity, and it is not the same as TFP.

[2] Alves et al. [7] also describe this situation through a research of the basic staple basket in the capital of São Paulo, from 1970 to 2009. These authors segmented their analysis into periods with specific characteristics. Besides the growth of prices in basic food in the first (1970-78) and third (2005-09) periods, the strong fall observed in the second period (1978-05) more than offset the prices increase. Generally, the total fall of prices in basic food was 21.9% from 1970 to 2009. This result was based on productivity increasing in agriculture (development of science & technology), which benefited low-income consumers.

[3] TFP can also be obtained from Fisher's index. Their results are practically identical. Fisher is also considered a superlative index.

However, focus on land helps to tie this approach with sustainable use of inputs. This index incorporates variables such as production, land area used and partial productivity [18]. It measures the area saved to produce the current quantity of food and meat, given the past technological pattern. According to [19] and [2], the LSE can be estimated through (4):

$$LSE_i = \left(\frac{P_{i1}}{A_{i0}}\right) - L_{i1} \quad (4)$$

Therefore, the LSE presents the impact of technical change on crop and livestock production over time, since it divides the quantity produced (Pt) in the final period (t = 1) by the productivity of the initial period (t = 0; i = {a (agriculture); l (livestock)}), subtracting the available land in the current period (L1). Thus, it is possible to verify what extent land size, a scarce resource, has been spared due to technological changes.

III. Results and Discussion

A. Brazilian TFP and Worldwide Comparisons

Table I shows the annual growth rates of TFP in Brazil for several periods, up to 2019. In the period 1975-2019, the average growth rate of TFP was 3.37%. This can be considered a high rate. In the 2014-2018 period, there was a severe drought that affected the main grain producing regions. This had a strong impact on productivity from 2010 to 2019, reducing its growth rate to 2.32% per year. The input indexes show that Brazilian agriculture is growing with less labor, less land and more capital. The product's growth rate of 3.80% per year is also a rate considered satisfactory for agriculture from 1975 to 2019.

In recent years, TFP has grown faster than it was in the past by comparing the first and the second waves of agricultural and livestock growth. From 1975 to 2019, labor and land have shown high annual rates of growth in productivity - labor, 4.25%, and land, 3.77%. The highest TFP growth was observed from 2000 to 2009 (3.80%) and in the past three decades in the period from 1990 to 2019 (3.67%). In the case of labor, this rate has been mainly due to the improvement in the quality of work. This occurs through training and through the advance of work tools. The gains in land productivity are essentially due to investments in research and adoption of new production systems that allow up to three crops to be obtained in the same area per year. Two most well-known production systems that have been used are the no-till system and the crop and livestock integration system. The gains in land productivity are mainly responsible for the huge land-savings effects. Rada et al. [20] and Rada and Fuglie [21] relate the TFP growth to the farm size as well. Education and crop specialization were also associated with higher TFP growth in Brazil.

TABLE I
Annual Growth Rates of Product, Inputs, TFP, Land, Labor and Capital Productivity in Brazil from 1975 to 2019 (%)

Growth waves	1st wave of agricultural and livestock growth		Different periods – 2nd wave of agricultural and livestock growth			2nd wave of agricultural and livestock growth	Total period studied
Period	1975-1979	1980-1989	1990-1999	2000-2009	2010-2019	1990-2019	1975-2019
Labor productivity	4.30	2.76	3.25	5.23	3.88	4.94	4.25
Land productivity	3.75	3.15	3.23	5.09	2.38	4.15	3.77
Capital productivity	3.58	3.12	2.22	3.84	1.38	3.00	2.96
TFP	2.93	2.27	2.66	3.80	2.32	3.67	3.37
Product Index	4.35	3.38	3.02	5.18	2.65	4.20	3.80
Input Index	1.38	1.09	0.35	1.33	0.33	0.52	0.42
Labor Index	0.05	0.60	-0.22	-0.05	-1.18	-0.70	-0.43
Land Index	0.58	0.23	-0.20	0.09	0.27	0.06	0.03
Capital Index	0.74	0.26	0.78	1.29	1.26	1.17	0.82

TABLE II
Annual Growth Rate of TFP by Selected Countries from 1975 to 2016 (%)

Country	TFP		
	1975-1990	1990-2016	1975-2016
China	2.74	3.54	3.08
Brazil	2.55	2.59	2.53
Chile	2.43	2.33	2.47
Spain	2.23	2.04	2.14
Germany	2.09	1.81	1.97
United States	1.44	1.97	1.74
Australia	1.78	1.40	1.54
France	1.53	1.58	1.49
Portugal	1.07	1.39	1.30
Japan	1.03	1.00	1.02
Argentina	0.26	1.42	0.85
World	1.02	1.68	1.35

Source: Prepared by the authors, based on USDA [22].

In relating the TFP and the product growths from 1990 to 2019, we find that the productivity gains contributed to 87% of Brazilian agricultural production growth; the remaining 13% comes from input growth. Thus, the growth of agriculture in Brazil is mainly based on productivity. Some international comparisons are presented in Table II. From 1975 to 2016, Brazil, China and the United States are major global producers of agricultural products, leading the growth in TFP in the analyzed period. However, there are other countries, like Chile, Germany, and Spain, that also grew at high rates since 1975.

Fuglie et al. [23] highlight the TFP rates achieved by Brazil and China. They attribute this growth to strong investments in research and the adoption of appropriate sectoral policies. The Brazilian agricultural frontier expansion has been developed through an intensive process of innovation. The world TFP rate grew faster after the 1990s than before. From 1990 to 2016, China and Brazil have led the growth. Nonetheless, China was

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and still is a net import country whereas Brazil has been an export global player.

Since the 1970s, expansion was based on the availability of rural credit, agricultural extension services, high investments in agricultural research, and cheap land. The growth of agricultural production in the following decade was marked by improvement and correction of soils, genetic upgrading and the development of an integrated management system, with predominance in the Cerrado biome, as deeply discussed by [2]. Embrapa (Brazilian Agricultural Research Corporation) introduced the agricultural liming technique to reduce soil toxicity. This innovation was followed by a better agronomic adaptation of crop to the tropical climate and more tolerance for Cerrado's acid soil. The mechanization was boosted, especially with the greater use of powerful tractors.

The soybean expansion has stimulated various agricultural chain, mainly for those that produced soybean meal (as animal feed) and soybean oil (for food and biodiesel industry). The production of this commodity in Brazil began to gain prominence in the 1970s, produced as a summer harvest option and intercalated with the production of wheat in the South. The crossbreeding techniques also led to develop high yield soybean varieties (and shortened lifecycle enabled two harvests per year). The research allowed the use of new seeds and cultivars that were more resistant to diseases, thus reducing crop losses as well as expenditures on agricultural defensives. Recently, it was occurred the expansion of the agricultural frontier in Matopiba (acronym that means Maranhão, Tocantins, Piauí and Bahia states) in the 1990s and 2000s.

The development of cattle, poultry, and hog industries were also a factor that stimulated soybean production as the demand for soybean meal increased. In addition, the soybean price has increased in the global market, which has contributed to promote this crop as an economic activity. Since then, the investment process on technology for the adaptation of soybeans under Brazilian climate conditions, also known as "tropicalization" of soybeans, has been initiated [2].

In 2003, the legalization of genetically modified soybean seeds caused a rapid and widespread adoption in Brazil[4]. However, it had heterogeneous effects on agricultural productivity across different regions, soils and weather characteristics. Biotechnology in agriculture also became a labor-saving and fostered industrialization [24].

Labor selection is important to allow developing areas to benefit from modern agricultural technologies. Cohen and Levinthal [25] developed an economic concept, firms' learning or absorptive capacity, which could explain farms' ability to identify, assimilate, and exploit external knowledge from the environment. Better skilled labor has contributed to improving farms' absorptive capacity. The labor selection relates to the use of modern inputs. In other words, the demand for skilled jobs in agriculture, as well as individuals with higher educational background, was affected by the changes in agricultural practices.

Despite the reduction of land use in the livestock sector, its production increased sharply. From the last three decades, the agricultural production registered huge increases, but with lower incorporation of land as economic factor. The gross value of agricultural and livestock production grew significantly over time, reaching US$ 159 billion in 2019[5], the highest statistic since 1990 [26]. From 1990 to 2019, the geometric growth rate was 6%, considered a high rate. Among the main factors that raised agricultural and livestock productivity over time, on one hand, the macroeconomic scenario was favorable related to market opening and monetary stabilization. On the other hand, strengthening of support programs (such as Pronaf[6], Moderfrota[7], Embrapa's breeding programs) and advances in bio- and geotechnologies, contributed to greater efficiency in the use of resources [13].

B. Total LSE (Agriculture Plus Livestock)

Before analyzing the LSE, it is important to describe the land use patterns in Brazil. Land is used for a variety of purposes: exploited areas, where the native vegetation was substituted by agriculture, forestry, and livestock; and areas where the native vegetation is maintained in varying degrees of conservation and protection. By the Forest Code, it determines the use and protection of native vegetation on public and private lands. This law requires all private rural areas to keep a percentage of native vegetation preserved as a Legal Reserve, for the protection of biodiversity, without any kind of financial compensation to the owner.

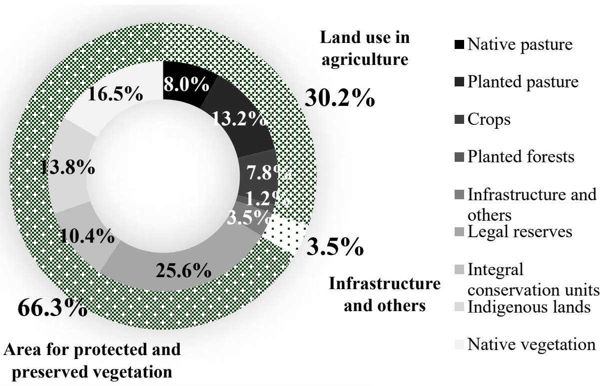

Fig. 1 Land use in Brazil (2018). Source: [27], adapted

As shown in Fig. 1, the area for protected and preserved vegetation corresponds to 66.3% of the national territory. The conservation units and indigenous land (protected areas) covered about 10.4% and 13.8% of the national territory respectively. The preserved area by farming exploitations is

[4] The main advantage of GM soybean is that it facilitates the use of no-tillage planting techniques and its herbicide-resistance. In addition, the genetically engineered soy can be applied directly on last season's crop residue which allows the saving cost among farmers due the labor saving to obtain the same output.

[5] We have converted this value from Reais into U.S. Dollars using the exchange rate as reported by the Central Bank of Brazil, at December 31, 2019 of R$ 4.03 to US$1.00.

[6] National Program for Strengthening Family Agriculture.

[7] Modernization of the Agricultural Tractors Fleet and Associated Implements and Harvesters.

roughly a quarter of the national territory (25.6%). In addition, 16.5% of Brazilian territory are covered by native vegetation. According to data, the land used in agriculture (30.2%) is predominantly planted pasture (13.2%), followed by native pasture (8%), crops (7.8%), and planted forests (1.2%). While the land use in agriculture in Brazil corresponds to less than one third of its territory, [28] described that the agricultural land in other countries (such as Argentina, China, France, Germany, and the United States) corresponded from 45% to 55%, except Canada (7%)[8].

Table III shows the data from agricultural and livestock sectors that are used to measure the LSE.

TABLE III
DATA OF AGRICULTURE AND LIVESTOCK PRODUCTION IN BRAZIL FROM 1990 TO 2019

Sectors	Variables	Units	Nom.	1990	1995	2000	2005	2010	2015	2019
Agriculture	Production	Million tonnes	P	467.4	548.6	590.7	615.0	950.4	1041.8	1075.4
	Area Planted	Million hectares	L	53.2	51.9	51.8	64.3	65.4	76.9	81.2
	Productivity	Tonnes / hectare	A	8.793	10.580	11.400	9.562	14.537	13.539	13.247
Livestock	Slaughtered animals	Million head	An	13.4	17.2	17.1	28.0	29.3	30.7	32.4
	Pasture area*	Million hectares	L	178.4	177.7	169.4	161.6	159.5	158.9	158.4
	Carcass weight	Kg / head	G	212.0	215.9	228.3	226.4	238.3	244.5	253.3
	Stocking rate	Head / hectare	S	0.07	0.10	0.10	0.17	0.18	0.19	0.20
	Productivity	Kg / hectare	A	15.892	20.864	23.015	39.275	43.739	47.164	51.898
	Production	Million kilograms	P	2835.8	3707.5	3899.8	6345.8	6977.5	7493.4	8218.9

*Interpolation of data from Agricultural Census 1995-1996, 2006 and 2017.

The sum of agricultural and livestock LSE from 1990 to 2019 was 400 Mha (41 million plus 359 million, respectively), which represented 47% of the national territorial extension. According to Fig. 2, the total Brazilian LSE was presented from 1990 to 2019. The dark area represents the total LSE, which is higher than the effective area in the last year.

The LSE of livestock production was estimated roughly at 359 Mha. The amount of land used in livestock activities remained relatively constant while production almost tripled. As in agriculture, this effect can be explained by the increase in productivity. The LSE on livestock farming have grown in almost all years analyzed.

Martha Jr et al. [19] state that the Brazilian cattle production has deeply changed in the last decades. The productivity gains in livestock explained 79% of the growth in beef production in Brazil during the 1950-2006 period, and supported an LSE of 525 Mha. The authors also highlighted that agricultural research effort has resulted in a spillover effect of knowledge and technology to farmers, which reflected in these productivity gains.

Although the LSE is more impacted by livestock management, soybean production has been contributing considerably to the LSE in agriculture. From 1990 to 2019, the soybean LSE represents 74% of the total effect (or 30.6 Mha). Lima et al. [29] analyze the planted area of soybean production in 2017/18 harvest. Through remote sensing techniques, the authors recognized that the new agricultural frontier of soybean is no longer in the Amazon, but in the last continuous areas of Cerrado as well as Matopiba. That is, according to the authors, the soybean production chain is focusing its development in a sustainable way, without the removal of forests.

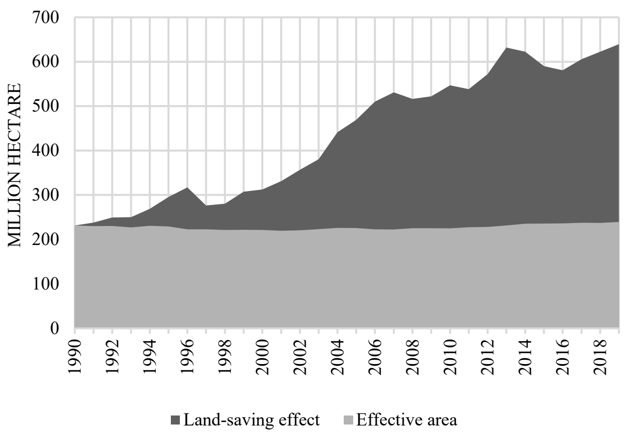

Fig. 2 Total LSE (LSEagriculture + LSElivestock) in Brazil from 1990 to 2019

Stabile et al. [30] highlight the importance of increasing productivity on medium and large exploitations through targeted investments, encouraging the adoption of technologies for sustainable intensification, and without expanding into new production areas. The recent frontier development is characterized by an increasing share of agricultural activities in the production portfolio, which could be the result of better access to modern technologies and markets, combined with forest governance induced by land scarcity for expansion [31]. Through intensification of cattle ranching and agriculture (rather than expansion in medium and large rural areas), Brazil is an example that is possible to curb deforestation and increase production simultaneously [30]-[33].

The integration crop-livestock systems are a technological solution to the sustainable criteria production because these systems have the potential to reclaim vast areas of degraded

[8] Chiavari and Lopes [28] compare the forest protection law and land use amongst the main food exporting countries. Among them, Brazil has the major forest coverage, equivalent to almost double than other countries. Brazilian law stands out in the international context, especially in considering the relevance that the country has in the global efforts to guarantee food security and the mitigation of climate change.

pastures while mitigating GHG emissions [34]. On one hand, the benefits of this system develop scope and scale economies reducing the economic risk due to the diversification of crops. The decision to adopt specialized or mixed systems should be based on relative prices of inputs and outputs. Economic returns depend on crop and livestock productivity. On the other hand, higher productivity increases the demand for modern inputs and capital. This demand for capital increases financial risk [35].

Fig. 3 shows the agricultural LSE disaggregated by microregions. It can be noticed that the predominance of the quantity of land saved is in the western part of the South and Southeast regions of Brazil, much of the Midwest and Matopiba and in some microregions of the North and Northeast. This performance could be associated with grain production and expansion through Cerrado biome.

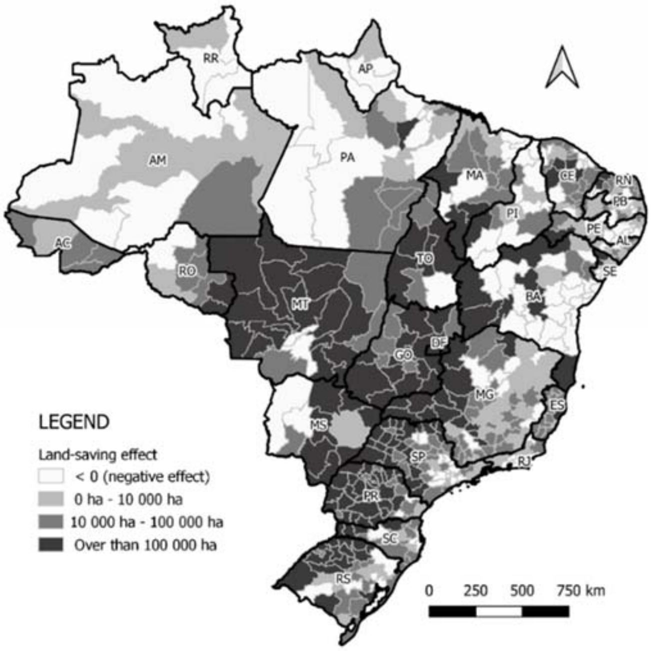

Fig. 3 Agricultural LSE per microregion in Brazil from 1990 to 2019

Brazil's emergence as the main global agricultural producer is often credited to productivity growth in the Cerrado [36]. The quantity produced of sugarcane, maize, soybean, orange, coffee, and cotton spread through this region. The different patterns amongst these crops of course are related to the level of the LSE.

Knowledge transfer and innovation are essential for sustainable rural development. The effectiveness of agricultural research and development is strategic for ensuring long-term development perspectives [37]. Dill et al. [38] describe that technology adoption and diffusion of innovation in beef cattle production are related to the participation of farmers in producer associations and communication between them and technicians.

Martha Jr et al. [19] describe the importance of incentives in innovations and financial support to stimulate the large-scale adoption of land-saving technology in Brazilian livestock. Tilman et al. [39] show that the land saving trajectory would minimize both land clearing and GHG emissions, as well as to provide a more equitable global food supply. Improvements in agricultural intensification through technology adaption and transfer, and enhancement of soil fertility would greatly decrease the GHG emissions and species extinctions (that otherwise would have resulted from land clearing), providing the preservation of biodiversity.

The livestock sector is essential for food and nutritional security of the world's population, and is also responsible for the livelihoods of about 1 billion poor people [40]. However, even with the significant amount of land saved from 1990 to 2019 (400 Mha), livestock farming still needs to overcome environmental effects, such as GHG emissions (CO_2). Fig. 4 shows the livestock farming and agricultural production per unit of emissions (CO_2 equivalent) in Brazil from 1990 to 2018.

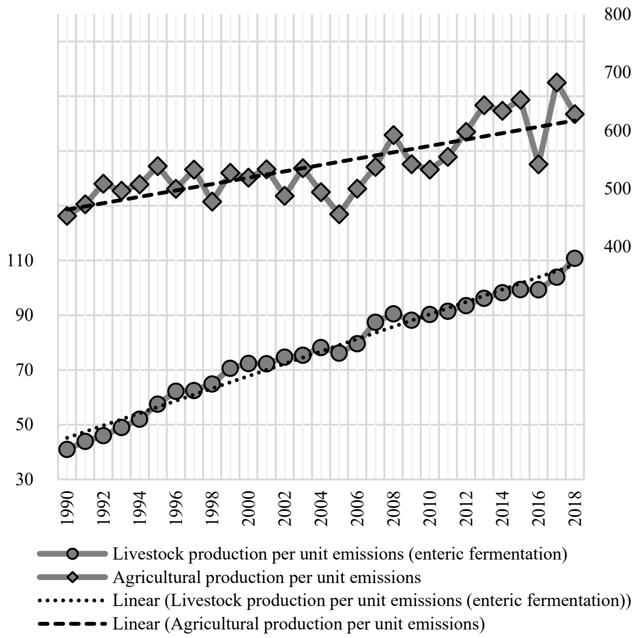

Fig. 4 Livestock farming and agricultural production (tonnes) per unit emissions (CO_2 equivalent, gigagram) in Brazil from 1990 to 2018. Source: Prepared by the authors based on FAOSTAT [41].

The bigger production per unit of emission, the better the sustainable development. The agricultural production grew from 453.1 (1990) to 628.3 tonnes/gigagrams (2018). Although Fig. 4 shows some oscillation, on one hand, the agricultural production per unit emission presents a growth trend line, with a geometric growth rate at 0.98%. On the other hand, the livestock production per unit emission almost tripled, from 41.0 (1990) to 110.8 tonnes/gigagrams (2018), following a geometric growth rate at 3.19%. When considering the sum of livestock and agricultural production per unit emission, it follows a geometric growth rate of 1.23%.

According to 42], beef cattle production can foster economic and environmental sustainability. Public policies have a positive impact in beef cattle production by improving farmers' perceptions of technology adoption. The investment on production practices such as pasture implantation and recovery, suitable pasture management, reduction on animals' slaughter age presents potential to GHG mitigation, reconciling productive, economic efficiency and environmental sustainability within the assumptions of public policies.

In the agricultural sector, the main activities responsible for the GHG emissions are enteric fermentation and agricultural soil. Therefore, actions in this sector can be a decisive factor for climate change mitigation, as well as to achieve sustainable development (see Vieira Filho [18]). Martha Jr et al. [19] state that advances on the sustainability path will ensure the continuity of LSE in livestock.

IV. Final Remarks

Agricultural expansion is still currently happening at a moderate pace. However, this process has occurred more intensified in different regions and times. The transformation of the Cerrado biome into arable land contributed considerably to this expansion process. Embrapa played a key role in the advancement of technology and applied research. Productivity gains generated a spillover effect throughout the production chain and different sectors.

The TFP indicates the efficiency of inputs combination in the agricultural production. From 1975 to 2016, Brazilian agriculture got 2.53 of TFP growth rate, while the global rate was 1.35% in the same period. When analyzing the labor, land, and capital productivity from 1990 to 2019, TFP growth in Brazilian agriculture was 3.67% per year (considered a high rate). We concluded that 87% of Brazilian agriculture product growth comes from the gains of productivity, while the rest of share comes from input growth.

The LSE estimates the amount of land saved based on a given yield in the past. Thus, the amount of preserved land by the increase in agricultural productivity between 1990 and 2019 was 41 Mha, which was mainly attributed to the soybean crops, of which its contribution corresponded to 74% of this number. In the livestock sector, 359 Mha were preserved in the same period. Pasture areas have suffered a reduction over the last decades while production increased. The amount of land used for crops had a slight increase since 1990.

We observed that both the agricultural and livestock production per unit of GHG emission grew over the past few decades. In order to mitigate climate change, a global agenda for sustainable livestock was created in 2010 to help spread new knowledge in order to promote the growth efficiency of the economic system. The LSE that was estimated in agricultural and livestock activities preserved 400 Mha overall, which represented 47% of Brazilian territory. Therefore, it can be inferred that investments in innovation and technology contributed to the expansion of the agricultural production frontier.

In recent years, the annual growth rate of TFP has slightly declined. This is an aspect that we must investigate in future research. In some of these years, Brazil has experienced losses in production due to drought or excessive rainfall during the harvest. There is also a possibility that a reduction in efficiency is occurring due to the natural difficulties of choosing optimal combinations of factors. In any case, these are hypotheses that deserve to be analyzed.

National system of innovation built over time has promoted the growth of agriculture and livestock farming. The adoption of new technologies and techniques (such as liming practices, soil fertilization, high yield varieties of seeds, productive new knowledge, no-tilled systems, crop-livestock-forest integration, biotechnologies, genetic engineering, mechanization, etc.) encouraged an expansion of the agricultural frontier in Brazil. The food supply growth caused a fall in prices, which benefited the low-income population. This is true especially in Brazil as food needs represent a high percentage of family income. Even we could measure different social impacts, this study focused on understanding economic and sustainable impulse. Productivity gains were the base of Brazilian agriculture and livestock growth.

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