Importance of Sugarcane in Brazilian and World Bioeconomy

Reges Heinrichs, Rafael Otto, Aline Magalhães, and Guilherme Constantino Meirelles

Abstract The area of sugarcane (*Saccharum* spp.) cultivation totaled 27 million hectares in the world and 10 million hectares in Brazil. Sugarcane is a valuable crop considering the potential to produce sugar, ethanol, biodegradable products, energy generation and food for animal production. In tropical conditions, high biomass production in the range of 150–300 Mg ha^{-1} year^{-1} can be achieved, depending on the management and production system employed. Due to great adaptation to different types of soil and environment, sugarcane could be produced in over 100 countries to supply biofuel and food to the world. Improvement in the production process adopted in Brazil in the last decade, including mechanical planting and harvesting, new methods of sugarcane planting, control of pests, diseases, nutrition and fertilization, has increased sugarcane yield in Brazil while improving work-conditions and social aspects of sugarcane cultivation. Therefore, the high potential production of sugarcane, its varied uses and its ability to be cultivated in regions with low economic and social development indicates that sugarcane cultivation could become a key source of income and improve life-quality in many regions. However, political and governmental organization is required to achieve this goal.

R. Heinrichs (✉)
College of Technology and Agricultural Sciences, São Paulo State University (UNESP), Dracena, São Paulo, Brazil
e-mail: reges@dracena.unesp.br

R. Otto
"Luiz de Queiroz" College of Agriculture, University of São Paulo (USP), Piracicaba, São Paulo, Brazil
e-mail: rotto@usp.br

A. Magalhães • G.C. Meirelles
Graduate Program in Animal Science and Technology, UNESP, Dracena, São Paulo, Brazil
e-mail: aline.magalhaes@live.com; gui_meirelles2312@hotmail.com

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1 Introduction

Sugarcane is a key crop in the Brazilian economy. Brazil has the world's largest cultivated area and is the world's largest producer of sugar and ethanol, being a world leader in the international market with the use of biofuels as an energy alternative. Brazilian production accounts for more than half the sugar traded in the world and production is estimated to increase 3.25% per year until 2018/2019. This corresponds to an increase of 14.6 million tons as compared to 2007/2008. Exports are expected to reach a volume of 32.6 million tons of sugar by 2019. Ethanol production should reach 58.8 billion liters in 2019, more than double the amount produced in 2008. Due to the increase in domestic consumption, internal consumption is projected at 50 billion liters and exports at 8.8 billion liters (MAPA 2010).

The success of Brazilian ethanol production started in 1975 with the creation of Proálcool to support the production of ethanol in Brazil. This was a good example of public policy for the development of biofuels, allowing Brazil to reach second position in ethanol production in 2008, and also to have the lowest production costs (Amaral et al. 2008).

Production of sugarcane in Brazil is estimated to increase by 3.3% per year until 2024, rising 884 Mt, i.e. 42% higher than production obtained in 2008, mainly due to the increase in cultivated areas. In the same period, the total cultivated area is estimated to increase by 2.9% per year. In contrast, the average yield fell between 2010 and 2014 due to climatic and management constraints, but should moderately increase during this projection (FAO 2015).

Energy production from sugarcane also plays an important role for the Brazilian economy. There are currently around 408 sugarcane mills in Brazil, and all of them are self-sufficient in the production process through burning bagasse. This results in a significant cost reduction. Some mills also present the cogeneration of electricity, allowing them to sell on the surplus energy, increasing income and reducing dependence on other sources of energy (thermal, hydroelectric, etc.).

The agroindustrial system of sugarcane is complex. The sector depends on suppliers of raw materials and high capital investment for sugar, ethanol and energy production (Neves and Conejero 2007). After industrialization, ethanol, sugar and energy are transferred to fuel distributors, electrical power systems, food industry, wholesale and retail, and export trading companies. The byproducts generated, such as filter cake, vinasse, and residual water, are used as bio-fertilizer in the production process, thus reducing expenses with synthetic fertilizers.

2 Planted Area and Production of Sugarcane

2.1 Brazilian Planted Area and Production

The Brazilian Agro-Energy Statistical Yearbook 2014, consolidating data from the agroenergetic chain of the Ministry of Agriculture, Livestock and Supply (MAPA 2015), presents the areas planted and harvested in the country during the period 2002–2013 (Table 1). The planted area increased more than 80% from 2002 to 2012.

Sugarcane production in Brazil in the 2014/2015 season reached 630 million tons, of which 575 million tons were grown in the South Central region, 48 million tons in the Northeast and 7 tons in the North (MAPA 2015). From this amount 35 million tons of sugar and 29 million cubic meters of ethanol were produced. The State of Sao Paulo, located in the South Central region of the country, accounts for 60% of total production of sugarcane in Brazil.

2.2 World Planted Area and Production

The total area cultivated with sugarcane in the world increased from 20.5 million hectares in 2002 to 26.1 million hectares in 2012. During this period, Brazil took first place among the main producing countries with a total area of 8.5 million hectares, followed by India (5.1 million hectares), China (1.8 million hectares) and Thailand (1.3 million hectares) in 2012 (Table 2).

Worldwide sugarcane production reached 1.8 billion tons in 2012. From that amount, Brazil reached 594 million tons, followed by India (348 million tons) and China (134 million tons) (Table 3).

Considering the expansion in area and production of sugarcane in major countries (Tables 2 and 3), it can be seen that from 2003 to 2012 the four major producing countries (Brazil, India, China and Thailand) consistently increased the area and

Table 1 Planted area and harvested area of sugarcane in Brazil

Year	Planted area (ha)	Harvested area (ha)
2002	5,206,656	5,100,405
2003	5,377,216	5,371,020
2004	5,633,700	5,631,741
2005	5,815,151	5,805,518
2006	6,390,474	6,355,498
2007	7,086,851	7,080,920
2008	8,210,877	8,140,089
2009	8,845,833	8,617,555
2010	9,164,756	9,076,706
2011	9,616,615	9,535,194
2012	9,424,615	9,407,078

Table 2 Sugarcane area harvested of main producing countries, in millions hectares

Country	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Brazil	5.4	5.6	5.8	6.1	6.9	7.0	7.4	8.0	8.4	8.5
India	4.5	3.9	3.7	4.2	5.1	5.0	4.4	4.2	4.9	5.1
China	1.4	1.4	1.4	1.4	1.4	1.6	1.7	1.7	1.7	1.8
Thailand	1.1	1.1	1.0	0.9	1.0	1.0	0.9	1.0	1.3	1.3
Pakistan	1.1	1.1	1.0	0.9	1.0	1.2	1.0	0.9	1.0	1.0
Mexico	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Indonesia	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
Philippines	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
USA	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Argentina	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.4	0.4	0.4
Colombia	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.4
Australia	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
South Africa	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Vietnam	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Guatemala	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3
Egypt	137.5	135.3	135.0	137.3	140.8	135.9	133.0	134.5	136.7	143.5
World	**20, 517.6**	**20, 154.5**	**19, 714.7**	**20, 611.5**	**22, 684.4**	**24, 085.4**	**23, 693.6**	**23, 784.1**	**25, 581.2**	**26, 088.6**

Source: FAO (2015); MAPA (2015)

Table 3 Sugarcane production of main producing countries, in million tons

Country	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Brazil	349.6	374.7	382.3	428.3	495.5	552.8	622.6	627.3	565.8	594.3
India	287.4	233.9	237.1	281.2	355.5	348.2	285	292.3	342.4	347.9
China	90.2	89.8	86.6	92.6	113	124.2	115.6	110.8	114.4	123.5
Thailand	74.3	65.0	49.6	47.7	64.4	73.5	66.8	68.8	96.0	96.5
Pakistan	52.1	53.8	47.2	44.7	54.7	63.9	50.0	49.4	55.3	58.4
Mexico	47.5	48.7	51.6	50.7	52.1	51.1	49.5	50.4	49.7	50.9
Philippines	31.0	33.5	31.4	31.6	32.0	34.0	32.5	28.0	30.0	30.0
USA	33.9	29.0	26.6	29.8	27.8	25.0	27.6	24.8	26.7	27.9
Australia	37.0	37.0	37.8	37.1	36.4	32.6	30.3	31.5	25.2	26.0
Argentina	22.1	20.9	24.4	26.5	24.0	27.0	27.0	26.2	27.1	25.0
Indonesia	24.5	26.8	29.3	29.2	25.2	25.6	26.4	26.6	24.0	26.3
Colombia	39.0	40.0	39.8	38.5	38.5	38.5	43.0	37.0	42.0	38.0
Guatemala	17.4	20.0	18.0	17.6	20.3	20.3	21.5	22.3	20.6	21.8
Vietnam	16.9	15.6	14.9	16.7	17.4	16.1	15.6	16.2	17.5	19.0
South Africa	20.4	19.1	21.3	20.3	19.7	19.3	18.7	16.0	16.8	17.3
Egypt	16.2	16.2	16.3	16.7	17.0	16.5	15.5	15.7	15.8	16.5
World	**1, 378.6**	**1, 340.9**	**1, 316.4**	**1, 421.9**	**1, 618.5**	**1, 7535**	**1, 693.5**	**1, 707.9**	**1, 819.4**	**1, 832.5**

Source: FAO (2015); MAPA (2015)

Table 4 Variation in area and production of sugarcane from 2003 to 2012

Country	Increase or reduction in area (%)	Increase or reduction in production (%)
Brazil	58.0	70.0
India	12.6	21.1
China	25.9	36.9
Thailand	17.6	29.9
Pakistan	–5.0	12.1
Mexico	14.1	7.2
Philippines	12.9	–3.2
USA	–7.9	–17.7
Australia	–24.4	–29.7
Argentina	18.6	13.1
Indonesia	36.0	7.3
Colombia	–12.2	–2.6
Guatemala	30.2	25.3
Vietnam	–5.0	12.4
South Africa	–2.1	–15.2
Egypt	4.4	1.9
World	**27.2**	**32.9**

Source: Adapted FAO (2015) and MAPA (2015)

production of sugarcane (Table 4). In Pakistan there was a reduction in planted area, although production increased, reflecting gains in productivity. On the other hand, countries with large potential for expansion of the crop, such as the USA, Australia, Colombia and South Africa reduced area and production; results that can be linked to specific agricultural policies of each country. However, these policies can change as demonstrated during the Paris Climate Change Conference (November, 2015) during which leaders of 195 countries pledged to reduce emissions of greenhouse gases. As a result, sugarcane is a crop with great potential for expansion due to its production of clean, renewable energy.

It is noteworthy that Brazil and India account for 52% of the total harvested area of sugarcane. The sum of the six highest sugarcane producing countries accounts for 70% of the total world area of sugar cane. Similar results are observed in the production of stems, with Brazil and India accounting for 51% of world production. With the addition of China, Thailand, Pakistan and Mexico this figure reaches 72% of world production of sugar cane (Fig. 1). Through analysis of these data it is apparent that sugarcane production is concentrated in a small number of countries.

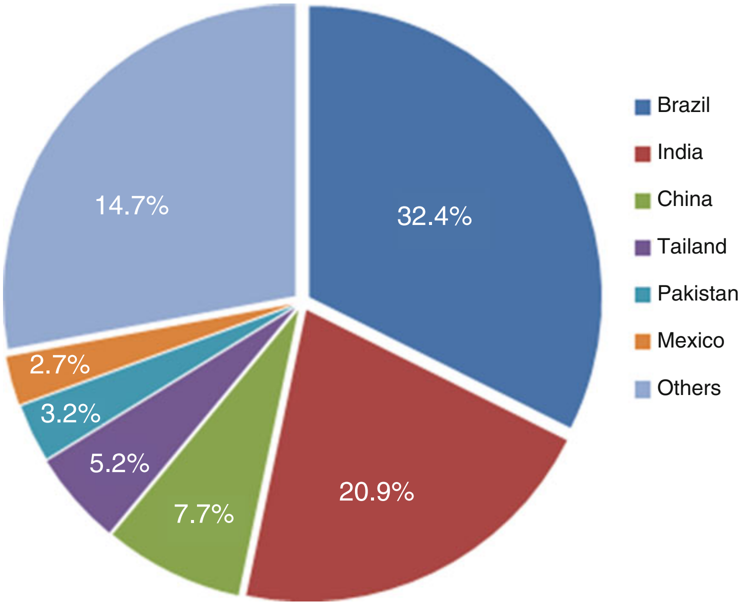

Fig. 1 Major producing countries of sugarcane. Source: Adapted by FAO (2015) and MAPA (2015)

However, there is a good possibility of expanding the area cultivated with sugar cane, by finding favorable climatic and soil conditions between latitudes 36.7° N and 31° S (Humbert 1968), covering the tropical and subtropical regions of the world. In this scenario, more than 100 countries could supply biofuels to 200 nations. Comparatively, currently only 20 producers provide fossil fuels to the rest of the world.

3 Technological Evolution in Cultivation and Productivity

Besides an increase in area, sugarcane production in Brazil also has the potential to increase due to development of technologies in planting and harvesting systems. This would allow an increase in production of bioenergy, technological advancement and also discovery of new products such as biobutanol, cellulosic ethanol and bioplastics, causing major changes in the industry's structure (Viana and Perez 2013).

The main advance in sugarcane production systems in Brazil in the last decade was the elimination of burning before harvest, with social, economic and environmental benefits. In the system without burning, the harvest is performed mechanically, leaving the crop residues (straw) on the soil surface. This conser-

Fig. 2 Pre-sprouted seedling (*left*) and planting in the field (*right*). Source: Authors

vational system has advantages such as soil protection against erosion and water loss, increase in carbon storage (Leal et al. 2013), improvement in soil fertility and reduction in CO_2 emission to the atmosphere.

New technologies such as no tillage and manure application have also been incorporated into the sugarcane system in Brazil. The no-tillage system, as compared to the conventional system, has increased productivity and improvement in soil conservation (Duarte Junior and Coelho 2008).

The use of vinasse provides higher concentrations of potassium in the soil, increasing the potential productivity, especially in sandy soil. The filter cake (press mud) provides better soil fertility by providing macronutrients and micronutrients, lower levels of aluminum, by acting as a corrective of acidity, providing higher levels of phosphorus and nitrogen in the plant. Sugarcane fields receiving either vinasse or filter cake display an increase in yields compared to non-amended fields, reduction in fertilizers usage and a decrease in costs.

Another developing technology is the planting of pre-sprouted seedlings, in order to reduce the amount of cane-bullets used during field establishment, as well as improved control of diseases (Fig. 2). Changes in plant spacing has also been evaluated, such as planting alternating double-rows (1.5×0.9 m) which allow controlled traffic, reduction in row compaction and thus increases in yield and longevity.

The removal of straw from fields for energy or second-generation ethanol production is in full expansion in many producing regions of sugarcane in Brazil (Cantarella et al. 2013). However, despite the economic appeal of this practice, sustainability issues need to be clarified, given the positive effect of straw in maintaining soil moisture, increases in C and N stocks and sugarcane productivity (Leal et al. 2013), especially in regions subjected to high temperatures and limited rainfall.

4 Employment in Sugarcane Production System

Historically, the Brazilian sugarcane industry was associated with poor working conditions, especially for manual harvesting of sugarcane. Currently, with the advancement of mechanized harvesting, which has already reached 85% of the cultivated area in the South Central region, working conditions have improved significantly.

However, there is concern related to unemployment that may be caused by mechanization. In this view, despite the reduction in jobs caused by mechanization, an increase in demand for better-qualified manual labour has been recorded. The mechanization process is creating opportunities for tractor drivers, truck drivers, mechanics, combine harvester drivers and electronics technicians, among others. As a result, this reduces the demand for low qualified hand-labor (Moraes and Momenti 2006).

The economic development of the regions varies due to different local or national actions, which could determine growth rates and can generate socio-economic inequality between regions. Some regions have advantages in structure and higher productivity, favoring the development of the sugar and ethanol industry and creating jobs.

5 Strategies to Increase Productivity and Sustainability

Brazil has a large area available for growing sugarcane, without causing damage to the production of other foods, as well as having production structures and distribution of technological products. The country incorporates the whole cycle of ethanol production, beginning in fields with high yields all the way to installation of equipment for the providers of this biofuel industry (MAPA 2015).

The expansion in sugarcane fields often takes the place of degraded areas with grains or pastures due to economic reasons, i.e. the availability of areas with low production efficiency transformed into productive areas with sugarcane cultivation. Sugarcane expansion is not occurring over areas of native vegetation. For recovery of degraded pasture, for example, areas can be used to plant soybean for one or more years to improve soil conditions for implementation of the sugarcane crop (Macedo and Seabra 2008).

In order to guide the sustainable expansion of sugarcane in Brazil, the federal government launched a policy based on environmental, economic and social factors. The *Agro-Ecological Zoning of Sugarcane* defined areas suitable for planting the crop considering climate types, soil, biomass, land slope and need of irrigation, among other characteristics (MAPA 2015). The study revealed an available area to expansion of sugarcane or other crops up to 65 million hectares, without the need for deforestation or encroaching upon protected areas such as the Amazon or Pantanal.

However, the increase in sugarcane production can not be based exclusively on an increase in the cultivated area but, in contrast, should be driven by increases in productivity. The sugarcane yield in Brazil increased from 43 Mg ha^{-1} in 1961 to 75 Mg ha^{-1} in 2013 (FAOSTAT 2014). The increased productivity of sugarcane comes from the improvement in varieties, plant protection treatments, changes in cultural practices, correct use of fertilizers, choice of regions with favorable climate and soil production and better control of weeds, pests and diseases.

6 Green Energy from Sugarcane

The production of ethanol from sugarcane in Brazil is a model that is well accepted because it is renewable and from biomass stocks for which the world has more sustainable agricultural production. The recent growth of the sugarcane industry is essentially due to the development of new technologies for the production of duel-fuel vehicles, or flex fuel, that is, vehicles capable of using both ethanol and gasoline, or even a mixture of both. The final aim is to increase the use of clean energy sources in order to reduce carbon monoxide emissions to meet the requirements of the Kyoto Protocol (Souza and Miziara 2010).

Internally in Brazil, sugarcane mills signed the "Environmental Protocol of the Sugarcane Sector" in order to conserve soil and water resources, protecting forests, recovering river basins, reducing the emission of greenhouse gases and increasing the efficiency of fertilizer use and agrochemicals products (Amaral et al. 2008). Reducing water in the industrial process is a requirement for sustainable ethanol production. Re-use of water in a closed circuit in the processing stage can reduce 90% of water usage (Salazar et al. 2013).

The cogeneration of energy has been an option for sugar and alcohol companies, due to the fluctuation of energy production by hydropower and the variation in rainfall, so cogeneration is a safe, cheap and environmental friendly option.

Competition for bagasse for energy generation, genetic and physiological improvement of sugarcane, and requirements for pre-hydrolysis of bagasse are variables that can affect second-generation ethanol (Raele et al. 2014).

Different levels of integration between first and second-generation ethanol are possible, using technologies for hydrolysis and fermentation of pentoses, resulting in great benefits due to higher ethanol production and better economic results. Second-generation ethanol has higher production of cane processed per ton, between 200 and 400 L ton^{-1} of dry matter in the fermentation and degradation of pentoses (Dias et al. 2012a, b).

The integrated system, based on the use of biomass and the combined cycle gasification used in sugar mills, provides better generation and power exportation than the direct consumption of bagasse combustion in the high-pressure steam cycle. This is beginning to be used in the sugar industry (Deshmukh et al. 2013). The increased volume of bagasse in the last few years represented 19.3% of Brazil's energy matrix in 2010, and all renewable energy sources accounted for 47.6%. Meanwhile, on the global scale renewable sources reached approximately 15.6% (Hofsetz and Silva 2012).

7 Byproducts of the Sugar and Ethanol Manufacturing Process

In the sugar and ethanol production process, the byproducts generated are reused in the industrial or agricultural processes, reducing production costs and environmental impacts. Bagasse is a fibrous residue from the extraction of the juice by the mills and the amount produced depends on the processed sugarcane fiber. Bagasse can be used as a source of fuel (energy) for boiler, pulp production and cattle confined feed.

Filter cake (or press mud) is a byproduct generated mainly in the production of sugar, in rates varying from 5 to 30 kg Mg^{-1} of sugarcane processed, depending on the extraction process of the juice. It contains around 75% of humidity and composting processes have been adopted to reduce humidity, dosages and quality of application to the fields. Filter cake is applied to the fields as a source of organic matter, phosphorus, nitrogen, calcium, sulfur and other nutrients, in planting or to the ratoon, in rates varying from 5 to 20 Mg ha^{-1} of dry matter.

The vinasse is the main byproduct of ethanol production. It is produced at a rate of 13 L per 1 L of ethanol produced and presents considerable amounts of potassium. This liquid byproduct is applied to sugarcane in the form of irrigation, supplying the whole amount of potassium required by sugarcane, as well as a portion of sulfur and nitrogen. Environmental legislation has advanced greatly in recent years and, currently, the industrial plants must draw up a vinasse implementation plan to be submitted annually to the environmental agencies to permit the milling. One strategy to adjust the vinasse application to environmental requirements refers to the concentration of vinasse. Equipment is available in Brazil for installation annexed to the mills, allowing concentration of between 8 and 10 times the vinasse. In this system, the dosages of conventional vinasse normally used (between 60 and 150 m^3 $year^{-1}$) are reduced to 6–12 m^3 ha^{-1} $year^{-1}$, with operational, economic and environmental benefits.

8 Animal Feed

Livestock activity is expensive and the production sector seeks lower costs of alternative food sources. Grinding sugarcane for feeding is a potential strategy, since the sugarcane production coincides with the period of lowest forage production (winter), when a loss of weight of animals is often observed (Murta et al. 2011). The sugarcane can also be used as silage, usually available in feedlots, being effective as forage for beef cattle. Cattle farmers have sought alternatives to reduce their production costs with feeding, since the confinement is a high-risk economic activity (Pinto et al. 2010). Sugar cane is commonly used in feedlots in the form of roughage food, being an economically viable alternative to substitute the silage when properly supplemented (Barros et al. 2010).

The sugarcane bagasse as a form of animal feed can be implemented with the use of treatments to improve digestibility, such as alkalizing agents that can been used for hydrolysis (Murta et al. 2011). Another technique that can be used is the ammonization of bagasse with urea to improve nutritional characteristics, by increasing the digestibility of fiber and crude protein content (Pires et al. 2004).

Final remarks
The sugarcane cultivated area is expanding rapidly in Brazil, but without replacing areas of native forest or other protected areas. Sugarcane yield has also increased consistently in the last decades in Brazil. Sugarcane is a renewable alternative to the production of sugar, ethanol and electricity. Second-generation ethanol requires further development, in order to allow ethanol production through enzymatic hydrolysis of bagasse or straw.

Brazil is the largest producer of sugarcane in the world and better farming practices are being developed to increase productivity. These include mechanical harvesting without burning, mechanical planting, soil amendments and fertilization practices, changes in the form of planting and the development of varieties adapted to the soil and climate of the expanding areas. Increased mechanization of planting and harvesting has offset the reduction of jobs by increasing requirements of qualified labor. The mechanization of harvest process has reduced historical problems of labor relations and improved social aspects of biofuel production in Brazil.

An international public policy to expand the sugarcane planted areas in the world is required in order to make sugarcane a commodity to meet the global energy demand. Brazil, due to its technical and scientific knowledge of the production chain, can contribute to the diffusion of agricultural and industrial technology needed for high productivity in a variety of soil and climatic environments, which would significantly advance sustainable energy production.

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