Sugarcane

The evolution of technological thinking in agriculture[1,2]

Marlene de Araújo[3]
Tarcizio Goes[4]
Renner Marra[5]
Mirian Oliveira de Souza[6]

Abstract – The purpose of this study is to show the importance of technological progress in sugarcane production and its impact on the Brazilian economy. The evolution is shown using the time line concept to separate the most important cycles of the sugar-alcohol sector, while economic, social and environmental indicators are used to measure the results. The indicators clearly point out the sector's progress and modernization. The study focuses on the advances achieved through the generation of new crop varieties with specific characteristics and the development of new products and byproducts of the sugarcane industrialization process. Special attention is accorded to the growth and increasing importance of the crop in the local and national economies, shown on the basis of the harvest values for the last ten years and production forecasts until 2020. The study concludes that the evolution of the agricultural and industrial technology in the recent past has enabled the sugarcane sector to become the most important and competitive in the world.

Keywords: sugar-alcohol sector, sugarcane and ethanol technology.

Introduction

The evolution of agricultural technology is best exemplified by sugarcane. The sugar-alcohol sector not only plants sugarcane, but also plants new knowledge arising from the seeds of innovation that generate economically viable ecological products. Although it coexists with an extremely positive economic and technologic panorama, the sector still needs to break old political, economic and structural paradigms.

> Technological innovation is the key to the growth, competitiveness and development of companies, industries, regions, and countries. It is also fundamental in determining the type of development of regions or nations and the manner in which such development will affect the quality of life of the population at large and of the different population groups, now and in the future (VIOTTI, 2001, p. 2).

The evolution of sugarcane production began with the production of sugar, progressed to ethanol from sugar and, at the present time, includes bioplastic or organic plastic products and cogeneration of energy. Its dynamics demonstrates the revolutionary nature of scientific progress in the sector. According to Thomas Kuhn (1975), the revolution occurs in leaps, rather than in a continuous line, as a function of pressure from the scientific and productive communities. The sugar-alcohol sector, as a result of economic pressures, entrepreneurial vision and capacity to perceive the demands,

[1] Original paper received on 5/9/2010 and approved on 12/9/2010.
[2] Study prepared for the Agriculture and Environment course of the University of Brasília Center for Sustainable Development (CDS/UnB)
[3] Analyst at EMBRAPA's Secretariat for Strategic Management (Embrapa/SGE).
[4] Researcher at Embrapa/SGE and doctoral candidate. E-mail: marlene.araujo@embrapa.br
[5] Analyst at Embrapa/SGE, economist. E-mail: renner.marra@embrapa.br
[6] Researcher at Embrapa/SGE; Master in Statistics. E-mail: mirian.souza@embrapa.br

was able to identify market anomalies and paradigms, which were interpreted as demands of society, as well as opportunities.

> A paradigm is a mental construct adopted to identify what is real before undertaking an in-depth study or investigation, which involves elements of methodological-scientific nature. What Kuhn calls normal science is the period in which one acts within a given paradigm shared by the scientific community. The scientists move forward, during this period, within the problems that the adopted paradigm helped identify. In so doing, they experience difficulties or problems which, at times, the paradigm is unable to solve, the so-called “anomalies”. When such anomalies get out of control, there is a crisis, which will only be solved through the emergence of a new paradigm. With the arrival of the scientific revolution, the way reality is seen changes, new paradigms are created. Kuhn describes the adoption of a new paradigm, at the individual level, as a sort of “conversion” that involves a whole possible set of reasons. After a new paradigm is adopted, a normal science period begins, which lasts until a new crisis is installed. (MAIA, 2010).

The chronology of sugarcane in the time line concept begins in 1515, when the first sugarcane stem cuttings arrived in Brazil from the Island of Madeira. The first sugar mill was built in Brazil in the São Vicente Captaincy in 1532 and, thereafter, other sugar mills were built in the captaincies of Pernambuco and Bahia, in the northeast of Brazil. The production of sugar was artisanal at the time and focused on a single product: sugar. Slave labor was used. The new varieties cultivated came from the Island of Java and were called Creola, Crioula or Mirim and Caiana sugarcane – introduced in Pernambuco by the Dutch. All those varieties were natural hybrids. A succession of varieties was planted in an effort to prevent the occurrence of diseases like gumming, among others. Mechanization was minimal, the fields were prepared using manual plows or draft animal plows. The sugarcane crushing machinery was pulled by oxen or slaves.

Three centuries later, cultivating the Roxa, Rosa, Salangor, Louisier, Bois Rouge, Cavangirie, Ubá, and Cristalina varieties, Brazil became the largest world producer and exporter of sugar, using hybrids with high sucrose storage capacity, enhanced pest resistance, vigorous, hardy, and tolerant to climatic events (GUIA..., 2009). According to Kautsky (1980, p. 37).

> [...] the problem for each producer is to choose from among the products sought that from which he will derive the greatest benefit, given the nature of the soil, the location of his lands and the transportation conditions, depending on the amount of capital available and the size of his property, etc. The various agricultural properties become specialized. Some prefer grain, others cattle, and still others fruits or grapevines.

Soil conditions, the location of the lands, ease of transportation, infrastructure, and more capital enabled production and determined where sugarcane was initially planted. From the Northeast, sugarcane traveled to the Southeast to become an important product in the balance of trade.

Method

The study was carried out on the basis of documentary research, the application of a statistical model called Arima (SOUZA; CAMARGO; 1996), i.e., an autoregressive model made up of mobile averages using agricultural production research data by municipality from the Brazilian Institute for Geography and Statistics (IBGE, in Portuguese) for the period 1949-2010, and the generation of estimates for the indicators.

Indicators are instruments which enable the evaluation and enhancement of the process whereby the policies that influence the rate and type of development of the regions are formulated and revised. Consequently, the indicators must be related to the economic processes and activities that constitute the sources and patterns of technological innovation and of other forms of change, whether economic, social, or technical, such as industrial processes, patents and inventions.

In the present study, the types of indicators more frequently used were economic and social in nature, such as production, share of the gross domestic product, harvested area, capacity to generate new markets, new jobs. The technological indicators were not studied in depth.

As for the environment, the most adequate indicator for sugarcane cultivation is the carbon balance, although the development of new types of products, especially those designed for a new ecological market, could be considered an indication of technological and environmental evolution.

Evolution by leaps

The decisions made by farmers are most often based on governmental decisions resulting from heated national and international debates which seldom correspond to a political agenda resting on logical and participative processes. The farmers usually decide how the production resources will be used based on factors such as the geographical location of the land, its topography, market demand, capital, capacity, and educational level of the available manpower, because of the growing demand for technically skilled workers. The major trends that cause the abandonment of old practices and the definition of a new orientation are much more characteristic of the urban centers than the countryside. According to Kausky (1980, p. 74), since the establishment of agricultural education in the large cities of Germany in the 19th century, agriculture has steadily suffered drastic interventions promoted by the cities. That constitutes the most eloquent illustration of how the rural regions completely depend on the urban centers today, and how progress in agriculture comes from the cities. The environmental policy decisions increasingly determine the new orientation of the agricultural policy. This statement is valid for decisions of science, the economy and foreign trade for agriculture and it is thus that the challenges arise.

In the case of sugarcane, the economic environment created the first challenge, which was making sugarcane the first export alternative for Brazil after the plummeting of coffee prices in the international market in 1929 and 1930.

> It is important to emphasize that the replacement of coffee plantations by sugarcane fields in the Alta Paulista region in the late 1970s was not due only to the Pro-Alcohol Program, but also, albeit to a lower extent, to a killing freeze that devastated the coffee-based economy of that region and of part of the State of Paraná. The freeze not only laid waste the coffee-based economy of the Alta Paulista region, but also made Paraná lose its standing as second-largest coffee producer in Brazil, since Paraná's freeze-associated harvest losses raised the State of Minas Gerais [from third-] to second-largest coffee producer. (SILVA, 2008, p. 12).

After the Second World War and the possibility of exporting sugar arose, sugarcane, which had begun expanding in the Northeast Region, also started to spread rapidly in the State of São Paulo. Thereafter, the São Paulo sugar industry prevailed, benefiting from its proximity to the consumer markets, and then won hegemony. The installation of machinery and fertilizer industries and of suppliers of industrial equipment (boilers, mills, etc.) and the use of technical assistance at the sugar refineries, which led to a significant technological transformation of industry and agriculture, were the main landmarks of the 1950s. In the following decade the sugar market expanded as a result of the international market prices and the export quotas of the producing countries were eliminated. The resources from the price increases were used to establish the Sugar and Alcohol Institute (IAA, in Portuguese) and the Pro-Sugar Fund, which financed the modernization of the sugar refineries, the main innovations being new mills and changes in the sugar production process (FIGUEIREDO, 2008, p. 40).

At the present time, São Paulo, including the Center-South region, accounts for 80% of the sugarcane produced in Brazil. Figure 1 shows the time line and the various cycles with associated changes.

In the 1970s, at the time of the import substitution drive in the machinery, fertilizer and pesticide sector, the integrated use of chemical products (as inputs) and machinery increased, helped along by greater access to credit lines from domestic sources. In addition, the production

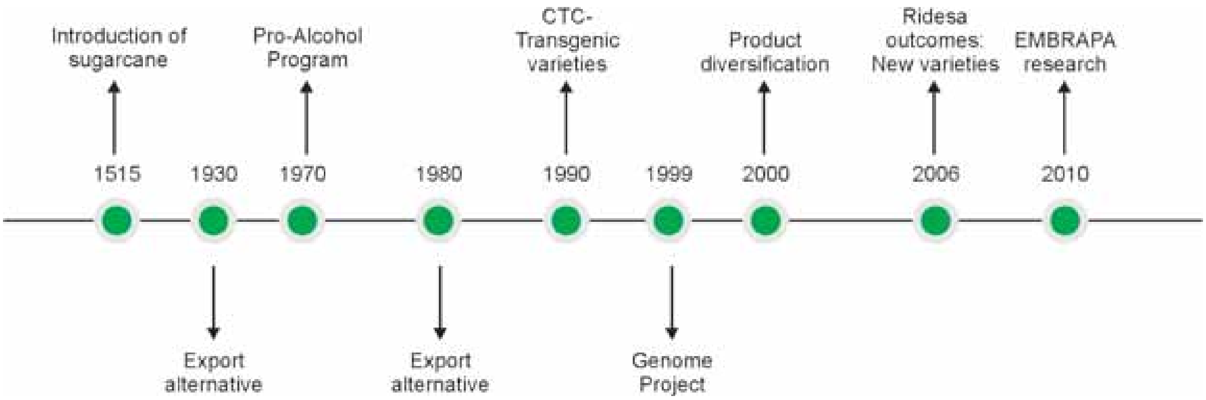

Figure 1. Time line.

strategy became more varied, in answer to the challenges of the oil crisis. The oil shock, together with the resulting rising gasoline prices, forced the creation of the National Alcohol Program (Pro-Alcohol) in 1975. This was the second challenge faced by the sugarcane sector and the Brazilian society. Thereafter, breeding programs increased in depth and scope and several, more productive varieties were released, and the industrial process achieved a high degree of modernization (SZMRECSÁNYI; MOREIRA, 1991, p. 72). Although the Pro-Alcohol Program did not totally achieve its objective, i.e., increasing ethanol production to meet the needs of the domestic and foreign markets in replacing gasoline, in accordance with the alternate fuel policy adopted at the time, it enabled the evolution of the sugarcane cultivation systems and industrialization processes, so that the crop reached a high technology level and there was significant return on the public investments on the sector.

The third challenge occurred in 1980, when the expansion of the crop into areas with unfavorable soil and climate conditions demanded new sugarcane varieties. The Copersucar and Inter-University Network for the Development of the Sugar-Alcohol Sector (Ridesa) programs developed sugarcane varieties more resistant to pests, diseases and water stress and adapted to the various regions.

The hybridization of sugarcane for the purpose of creating new varieties was a latecomer in Brazil, since no studies about the inflorescence and the possibility of producing fertile seeds existed by the end of the 19th century. In the late 1990s, the Sugarcane Genome Project enabled the identification of 50,000 genes linked to characteristics such as development, production and sucrose content, resistance to several types of stress and other features that increase the commercial yield of sugarcane. Also in the 1990s, the Copersucar Technology Center (CTC) was the first to obtain transgenic varieties with characteristics that enabled cultivation in restricted areas. The first results of the Sugarcane Genome Project emerged in 1999 and made it possible to expand the cultivation of sugarcane to the Southeast and Center-West regions of Brazil. At the present time, breeding programs use molecular markers and biotechnology. (GUIA..., 2009, p. 3).

The fourth challenge is currently underway. It can be described as the diversification of products, the replacement of polluting products, such as plastics, with organic plastics or bioplastics and the strengthening of sugarcane as a source of energy. Current efforts focus on bioelectricity, alcohol chemistry, carbon credit commercialization, extending the frontiers of technology.

The use of advanced technologies in the process engineering area, chemistry, investments in research and development, as well as partnership arrangements between industries that have products in the public domain, such as reservoirs and pipes, and industrial automation companies, project engineering companies, and equipment manufacturers, has led to productivity increases, cost reduction, greater competitiveness, more jobs and higher incomes, and a whole array of business opportunities, with increasingly positive impacts on the economy of the country.

Throughout history agricultural management also became specialized. Sugarcane is planted in practically all types of soils, from the sandiest to the most clayish. Sandy soils are usually poorer from the chemical standpoint, which is prejudicial to the plants' absorption capacity and makes them more susceptible to pests. The type of soil does not interfere directly on the propagation of the pests, but can favor their action, since the chemical characteristics of the soil can facilitate or impair the plants' capacity to survive. Consequently, the selection of the variety best adapted to each soil and climate condition is important, because the variety would be more able to resist or suffer less from pest attacks. Air temperature affects the development of sugarcane. In temperatures ranging from 22 °C to 30 °C sugarcane has the highest rates of growth and biomass accumulation. Above 38 °C, those rates drop down to practically zero. In areas with temperatures below 19 °C and freeze risk in excess of 20%, problems begin. Water deficiency from 180 mm to 400 mm p.a. indicates the need for irrigation (AQUECIMENTO..., 2008). Figure 2 shows the regions of Brazil with favorable sugarcane planting conditions from March to June and the municipalities with favorable planting conditions in September and October.

At the present time, the production environment is monitored using sample taking procedures, and the control measures are taken as a function of each situation. Emergency or intensive irrigation measures are taken in the case of draught.

Sugarcane and banana are among the many domesticated plant species in the modern world according to Diamond (2008, p. 125). His research points to the domestication of sugarcane around 7000 B.C. by New Guinea farmers. At the present time, sugarcane is undergoing the most intense intervention of all plant species, as economic interests drive man to adapt it to non-alimentary purposes. In 2005, the Campinas Institute of Agronomy (IAC) released a variety called IAC 2050, which is being gradually adopted by farmers. In addition to its high sucrose contents, good food conversion ratio, excellent yields, longevity of the stands, and increased harvest productivity, an advantage of this variety is the spontaneous separation of the straw, which reduces the need for burning the leaves, thus attenuating the environmental impact of soot in urban centers. It also propitiates soil nutrition, facilitates mechanized harvesting and reduces production costs.

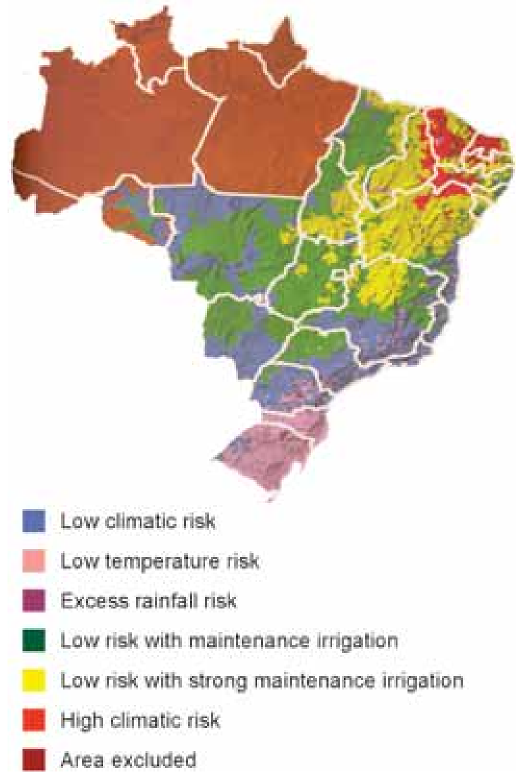

Figure 2. Regions of Brazil with favorable planting conditions.

Source: Aquecimento... (2008).

The third challenge – the development of sugarcane varieties adapted to diverse regions – was met in 2006 with the adoption of new types of sugarcane resistant to frost, which make it possible to advance milling from March 21 to February 15. Earlier processing has enabled productivity increases and diminished frost risks by 60% through the use of the early varieties. In 2006, those varieties had already been planted over 12,300 hectares (PORTAL DO AGRONEGÓCIO, 2010).

EMBRAPA, in partnership with the Japanese International Research Center for Agricultural Sciences (JIRCAS), is engaged in a project aiming at the insertion of a promising gene (DREB) of draught tolerance into five crops important to Brazil from the agricultural standpoint, among which sugarcane for the Northeast Region. Other research projects at EMBRAPA focus on increasing nitrogen fixation in sugarcane stands with a view to obtain 2nd generation ethanol and generating more productive varieties for the Northeast and North regions of the country.

Sites where low temperatures and intense cold prevail, often subject to frost, are not adequate for sugarcane farming, since the crop is sensitive to temperate climates, as is the case of the State of Rio Grande do Sul. The development of early varieties resistant to cold and frost enables the expansion of sugarcane into the South Region of Brazil, where the crop is being planted in areas degraded by cattle operations. That is the fifth challenge. There are no outcomes yet. Researchers at the Federal University of Paraná and EMBRAPA Temperate Climate are working on developing sugarcane varieties adapted to the State of Rio Grande do Sul, and their results should be available by 2014. The main feature of the variety to be planted in the cold South should be a cycle shorter than normal, since sugarcane has enormous difficulty growing in the winter and a way of bypassing that problem would be to shorten the plant's growth cycle.

Figure 3 shows 427 plants, of which 249 are mixed operations (they produce both alcohol and sugar); 162 plants producing only alcohol; and 16 plants that produce only sugar. The largest concentration of sugar/alcohol plants is found in the Center-South, in the states of São Paulo, Minas Gerais, Mato Grosso, Mato Grosso Sul, and Paraná. (BRASIL, 2010).

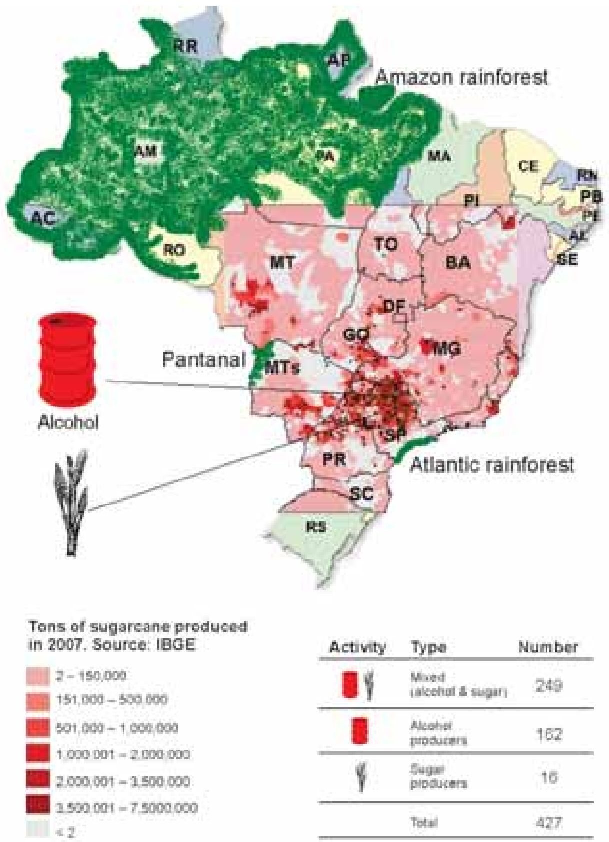

Figure 3. Producing units.

Source: Map data (2010) and Unica (2010).

The evolution of industry as a lever for the sugar-alcohol sector

The integration of sugarcane industry and sugarcane farming is both horizontal and vertical. The capital goods sector has evolved to meet the demands of agriculture, creating specific equipment and industrial processes for the sector, which vary from planting to harvesting, and from harvesting to different types of industries. One of the main innovations was the Local Production Arrangement, which involves partnerships between low-technology and public domain companies and aggregate technology companies, process and design engineering companies and machinery manufacturers.

> [...] the characterization of capital goods is functional: capital goods are products used to make other products, repeatedly. They are different, therefore, from productive inputs, which are transformed along the production process and, conventionally, are identified with machinery and equipment. Thus, the capital goods industry (CGI) manufactures the machinery and equipment used by the other sectors to produce goods and services (VERMULM, 1993 p. 2).

There are two types of mechanical capital goods – serial goods and made-to-order goods. The latter type, also called customized goods, are designed for a specific company, they are tailor made, which demands equipment, manpower and production routine flexibility from the manufacturer; technical and scientific progress in such a production system determines the company's survival. In the case of the sugarcane sector, the arrangements made as a function of the different types of companies or industrial activities generate gains in competitiveness as a result of the innovation and cooperation strategy which, in turn, generates high industrial capability and regional development. The degree of competence and innovation of the sector is so high that it is possible to order a complete industrial unit to set up a sugar refinery, and that refinery can be integrated from biodiesel to ethanol to bioelectricity. The industrial processes have evolved with the new requirement to reduce environmental impacts; at the present time, there are processes with input reduction and with sugarcane reuse and cleaning in dry cycles. Figure 4 shows the types of equipment industries that serve the sugar-alcohol sector.

The innovation and cooperation that accompanied the enhancement of the industrial process have enabled the development of new products, the diversification of the market and the substitution of polluting products, so that there has been an increase in productivity and liquidity and ensuing new business alternatives and opportunities. The popular maxim "everything from an ox can be put to use, event its bellow" can now be adapted to sugarcane: "everything from sugarcane can be put to use, even the straw".

The main achievement has been transforming the byproducts, such as bagasse, straw, terminal panicles, and other plant remains, into essential raw materials. Sugarcane biomass is used today to generate electricity (bioelectricity), a rapidly growing use in Brazil, as another clean, renewable alternate source of

Public domain	Mixed	Engineering	Manufacturers
Low technology equipment	Manufacture equipment with more aggregate technology	Design of equipment and processes	Equipment with greater aggregate technology Equipment for setting up refineries
Reservoirs, pipes, chains	Industrial automation	Design sales	Follow the guidelines of the engineering company
Own know-how No research (R&D)	In-house R&D centersInvest in product and process innovation	Carry out R&D Operate in partnership with the manufacturers	R&D in partnership

Figure 4. Typology of the sector's industry.

Source: Designed by the authors on the basis of Liboni and Toneto Júnior (2010).

energy. Each ton of milled sugarcane generates from 240 kg to 280 kg of bagasse, used as an energy source to feed the boilers, generating both thermal and mechanical energy. The thermal energy is used in the sugar and alcohol production process and the mechanical energy is consumed in the sugarcane crushing process or transformed into bioelectricity by means of a generator. The excess energy can be used at the plant or sold to a utility company. This process is called cogeneration, i.e., simultaneous generation of mechanical and thermal energy from a single fuel.

Data for the Ministry of Mines and Energy and the Energy Research Company (EPE) (EPE, 2010, p. 24) show that 47.3% of all energy consumed in Brazil come from renewable sources; sugarcane accounts for 18.1% of the energy mix, ahead of hydroelectric power, therefore. Forecasts for 2015–2016 point to 75% of the sugarcane bagasse and 50% of its straw supplying 15% of all energy needs in Brazil.

Nevertheless, the major breakthrough in the use of sugarcane biomass is cellulosic ethanol or bioethanol, also called 2nd generation ethanol, soon to become a reality. The bioethanol project is being developed at the Federal University of Rio de Janeiro (UFRJ). In general terms, this means there is a systematic effort to identify microorganisms that could produce an enzymatic complex able to hydrolyze the sugarcane bagasse. Hydrolysis is a process whereby glucose, a six-carbon sugar, can be extracted from cellulosic material. Since all plants contain cellulose, whoever first masters the process could, in the future, produce ethanol from various raw materials, such as corn and wheat straw and even some types of grass. In the case of the Brazilian project, the scientists want to extract the cellulose from a specific agricultural residue: sugarcane bagasse. (SIMÕES, 2010).

Also regarding energy, the recently released sugarcane diesel is being tested by Mercedes Benz, opening a new energy frontier.

In addition to the aforementioned alternatives in the energy sector, sugarcane bagasse is also used in animal rations, paper, furniture boards, and organic fertilizers, among others. In the alcohol chemistry sector the production of green plastic has already attained industrial scale, and the production of PET bottles should begin as soon as the major soft drink manufacturers make the decision, making sugarcane biomass an increasingly used raw material in industrial processes.

Current situation and results

Expansion of sugarcane farmed area and production in Brazil

The farmed area, production and average yield data for the study's comparative analysis were obtained in IBGE's Municipal Agricultural Research and cover the period 1931–1987. The study also includes data commented in the document *Estatísticas Históricas do Brasil: séries econômicas, demográficas e sociais de 1940 a 1988* (IBGE, 1990), cited in *Estatísticas do século XX* (IBGE, 2003), as well as annual data from the Applied Economic Research Institute (Ipea) (2010).

An analysis of the data enabled the authors to conclude that sugarcane farming has expanded significantly since its introduction into Brazil. On the basis of a historical series of sugarcane farmed area and production data from 1940 to 2010, the rate of growth of the crop becomes evident. Figure 5 shows the sugarcane farmed area during that period (CONAB, 2010; UNICA, 2010). In 1940, the sugarcane farmed area extended over 564,000 hectares, while the forecast for 2010 is 8.8 million hectares. Genetic breeding has been the greatest contribution, as shown by the rising curve beginning in 2001, when 4.9 million hectares of sugarcane were harvested.

Genetic breeding programs have also contributed to the increase of production. In 1940 Brazil produced 22 million tons, with an

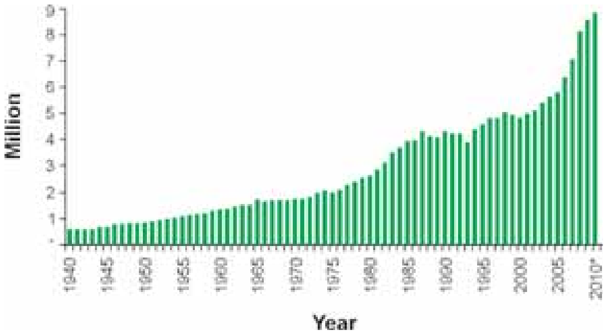

Figure 5. Sugarcane planted area from 1940 to 2010 (million hectares).

Source: IBGE data (1990, 2003, 2010).

*Forecast.

average yield of 39.4 t/ha; in 2010, estimates point to 698 million tons, with an average yield of 79.1 t/ha. The curve continued rising in 2001, with 344 million tons and an average yield of 69.4 t/ha. Figure 6 shows the growth of production during that period. (CONAB, 2010).

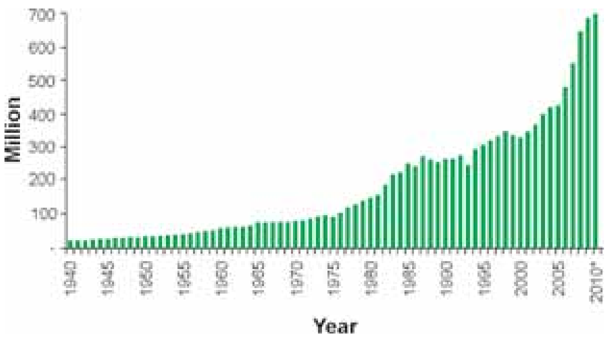

Figure 6. Production increases from 1940 to 2010 (million tons).

Source: IBGE (1990, 2003, 2010) and Conab (2010) data.

The average sugarcane yield in Brazil at the present time is 80 tons/hectare/year. Figure 7 shows that the yield in 1940 was 40 t/ha. The leap occurred in 1982, 12 years after the implementation of the Pro-Alcohol Program and the adoption of new CTC varieties. After the strengthening of genetic breeding research, the growth curve rose steadily.

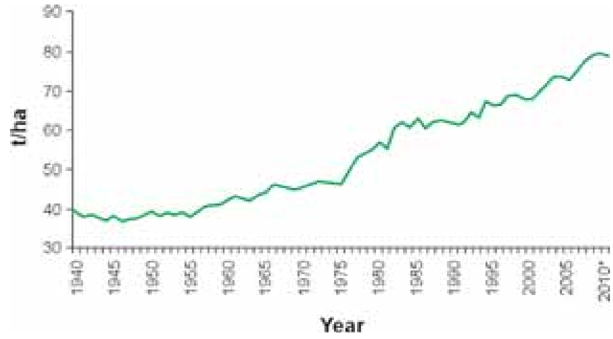

Figure 7. Average yield from 1940 to 2010 (tons/hectare).

Source: IBGE (1990, 2003,2010) and Conab (2010) data.

Nevertheless, research results show that sugarcane productivity can still increase considerably. Under adequate climate and soil conditions and using technology some producers harvest 150 tons/hectare/year. New cultivation practices and a new system of planting and fertilizing, together with new genetically improved varieties, make it possible to increase sugarcane yields and competitiveness levels in Brazil, although with scant impact on total average productivity.

The estimated sugarcane farmed area for the period 2011–2020, calculated by the EMBRAPA Secretariat for Strategic Management using the integrated autoregressive model of mobile averages, follows an upward growth trend. Figure 8 shows growth from the current 8.8 million hectares to 9.6 million hectares in 2020.

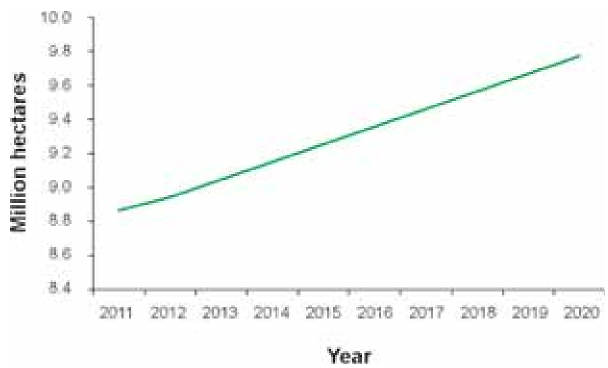

Figure 8. Sugarcane harvested area forecast for the period 2011–2020.

Source: IBGE data (1990).

Production foresc asts for the period 2011 – 2020 using the same model point to an overall increase from 700 million tons to more than 760 million tons. Figure 9 shows the production growth trend in million tons.

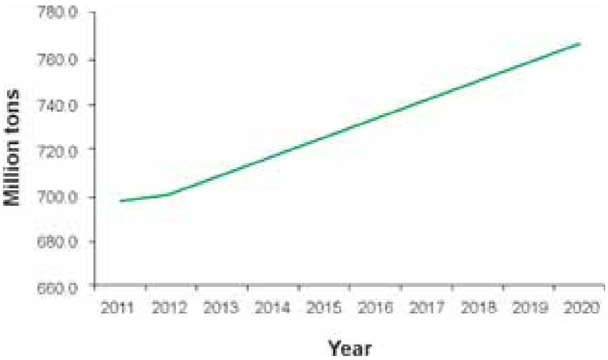

Figure 9. Estimated sugarcane production for the period 2011 - 2020.

Source: IBGE data (1990).

Table 1 provides the results of a simulation of the average yield growth for the period 2010 – 2020 and shows the possibility of a restraint to the average yield growth, despite a small increase of the sugarcane farmed area and number of tons produced. Future yield increases would require the use of biotechnology to provide increasingly productive varieties in the areas currently farmed because of the sugarcane zoning restrictions and the forestry code.

Table 1. Estimated growth of average yield from 2010 to 2020.

Year	Area (million hectares)	Production (million tons)	Average Yield (t/ha)
2010	8.83	698.43	79.1
2011	8.87	697.72	78.7
2012	8.95	700.86	78.3
2013	9.05	709.10	78.4
2014	9.15	717.33	78.4
2015	9.26	725.57	78.4
2016	9.36	733.81	78.4
2017	9.46	742.04	78.4
2018	9.57	750.28	78.4
2019	9.67	758.51	78.5
2020	9.77	766.75	78.5

Source: IBGE (1990) e Conab (2010) data.

Benefits of the sugar-alcohol sector

The technological progress achieved by the sugar-alcohol sector has contributed to regional and national development. The Gross Domestic Product (GDP) of the sugar-alcohol sector is US$ 28.15 billion, equivalent to almost 2% of the national GDP, or practically all the wealth generated, in one year, by countries such as Uruguay (US$ 32 billion) (UNICA, 2010).

Considering the new jobs generated by sugarcane farming, resulting from the refined and unrefined sugar plants, sugarcane milling and ethanol production in 2008, the sector had 1.28 million people under contract, equivalent to 2.15% of all jobs in Brazil (UNICA, 2010).

According to Liboni and Toneto Júnior studies (2010), most refinery equipment manufacturers are located in the municipalities of Piracicaba and Sertãozinho. Each municipality has its own specificities regarding the sugar-alcohol sector.

> The first consideration is that the Municipality of Piracicaba is significantly larger than Sertãozinho, with a 3.5 times larger population; although the population of Sertãozinho had the largest growth rate in the last period: 32% vs. 26% from 1991 to 2007. The two municipalities have high urbanization rates, good human development indexes, with emphasis on the favorable evolution of both municipalities in recent years, when Piracicaba rose one position in the state-wide classification and Sertãozinho, 15 position. According to their HDI, both municipalities placed in the high human development range. Their per capita incomes are high and even propitious when compared with the country's average: 37% higher than the mean in the case of Piracicaba and 52%, in the case of Sertãozinho. An important point is the high share of the Industrial GDP in both municipalities, namely, 32% in Piracicaba and 43% in Sertãozinho, which reflects the basic characteristic of both municipal economies being closely linked to industrial activities. It is also necessary to emphasize

their low share of the agricultural GDP, although both municipalities are located in regions known for their strong agriculture and their industries being directly linked to the agricultural sector, either through the processing of sugarcane, or by supplying the sugarcane sector. (LIBONI; TONETO JÚNIOR, 2010, p. 5).

Table 2 contains data compiled by the United Nations Development program (UNDP) on the basis of an article by Liboni and Toneto Júnior on regional development presented at the *1st Workshop of the Observatory for the Sugar-Alcohol Sector* in April 2008.

The contribution of sugarcane farming to the Carbon Balance is an important indicator of the benefits of the crop. Sugarcane draws carbon from the atmosphere through photosynthesis. According to Biagi Filho (2010)

"[...] during its average vegetative cycle of 14 months, sugarcane absorbs more CO_2 than an equal area of mature native forest. When it achieves maturity and stops growing, the sugarcane is harvested, freeing the area for a new cycle."

After the release of flex-fuel automobiles in Brazil, studies by the Environmental Sanitation Technology Company of the State of São Paulo (CETESB) showed that the carbon monoxide (CO) emissions of cars being operated prior to 1980 – when gasoline was the only fuel being used – dropped from more than 50 g/km to less than 1 g/km in 2000, as a result of the technological changes made to Brazilian automobiles. (PORTAL DO AGRONEGÓCIO, 2010).

According to Andreoli and Souza (2007), comparative studies of oil, corn and sugarcane concluded that ethanol from sugarcane or cellulose substantially reduces gas emissions and oil consumption. Ethanol use can reduce greenhouse gases by as much as 65% (GEEs). (EPE, 2010).

Another critical environmental theme associated with sugarcane farming is crop burning at harvest time. Neves and Conejero (2010, p. 207), quoting data from the National Institute for Space Research (Inpe) and the Sugarcane Industry Union (Unica), assert that the percentage of the area harvested without prior burning rose to 34.20% in 2006–2007; to 46.60% in 2007–2008; and to 49.10% in 2008–2009, in areas with gradients below 12%, which can be machine-harvested.

Table 2. Regional development promoted by the capital goods industry of the sugar-alcohol sector.

Indicator	Year	Cities	
		Piracicaba	Sertãozinho
		Amount	Amount
Population	1991	283,833	78,776
HDI – State-wide ranking	1991	22	44
HDI	2000	0.836	0.833
HDI – State-wide ranking	2000	21	29
GDP Industry	2005	1,853,196	807,870
GDP Agriculture	2005	6,244	36,173
GDP Services	2005	1,996,099	815,635
Per capita income R$	2005	15,971	17,794
Population	2007	358,108	103,558

rce: Based on Liboni and Toneto Júnior (2010).

Conclusions

The modernization of the sugar-alcohol sector was based on genetic breeding, improved cropping practices and innovation and cooperation schemes in the capital goods sector. As a result of the new varieties obtained by the breeding programs, Brazil has been able to increase sugarcane productivity by more than 50% in the last 30 years. Since the early 1990s, the use of biotechnology has enabled the compilation of the first genetic maps of the crop and the production of the first genetically modified sugarcane plants.

The sector's capacity to reinvent itself led to the emergence of a specific, specialized industry that has driven the development of the sugarcane regions. It should be emphasized that modernization occurred as a function of the intervention of the Estate, which promoted the integration of industry and agriculture, as well as the enhancement of the financial and organizational capacity for agricultural modernization through credit lines and cooperative arrangements. It also promoted the development of research and extension systems to further the existing knowledge about sugarcane varieties and industrial and agricultural processes and organized the production flow by means of tax, credit and commercialization policies.

The continued intervention of man in nature is inevitable. The history of agriculture began in the Fertile Crescent with the initial domestication of eight crops, called founder crops. The peoples who inhabited the Fertile Crescent rapidly put together a powerful, balanced biological package for the intensive production of foodstuffs. That package included three grains, four legumes, four domestic animals and flax, as a source of fibers and oil. (DIAMOND, 2008, p. 142).

The new cold-resistant varieties, another product of human intervention in nature, indicate that sugarcane farming will be spreading to the South Region and northern Mato Grosso do Sul, while the draught-resistant varieties should strengthen sugarcane farming in the Northeast Region of the country. Despite the expansion of the crop, the plantations are 2,500 km from the Amazon Region (in the south to north direction) and 2,000 km in the northeast to north direction.

The sugar-alcohol sector's dependence on mechanization and skilled manpower; the need for infrastructure; and the logistics, communication networks and state-of-the-art technical assistance also corroborate the view that the sector is migrating toward the South and Center-West regions of the country.

Recommendations

Any innovation process that promotes economic and social development should be part of a national development plan based on the pattern of evolution of the sugar-alcohol sector. Consequently, public policies that promote research focused on integrated innovation for agriculture, industry, academe, and commerce are strongly recommended. Such policies should be implemented through sectoral development funds for the development of human resources through technical training aiming at the accumulation of knowledge and the generation of methods, processes and technologies that make it possible to reduce obsolescence and promote sectoral growth. In the case of the sugar-alcohol sector, the training programs should be permanent and focus on the actual operationalization of the current system, which is highly technical but lacks the required technical manpower. Furthermore, the programs should include measures to retain the knowledge acquired, strengthen the competitive advantage achieved and create future opportunities.

References

ANDREOLI, C.; SOUZA, S. P. Cana-de-açúcar: a melhor alternativa para conversão de energia solar e fóssil em etanol. **Revista Economia & Energia**, [S.l.], v. 59, p. 27-33, 2007. Disponível em: <http://ecen.com/>. Acesso em: 5 ago. 2010.

AQUECIMENTO global e a nova geografia da produção agrícola no Brasil. São Paulo: Embrapa: Unicamp. 2008. p. 47. Disponível em: <http://www.embrapa.br/publicacoes/tecnico/aquecimentoglobal.pdf/view>. Acesso em: 4 ago. 2010.

BIAGI FILHO, M. **Externalidades da cana**. [Única. Opinião]. Disponível em: <http://unica.com.br/opiniao/show.asp?msgCode={785C0D5F-5250-4EC9-A66E-4CD6FB8D417C}>. Acesso em: 5 ago. 2010.

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento (Mapa). Departamento da Cana- de-Açúcar e Agroenergia. **Relação de usinas e destilarias cadastradas**. Disponível em: <http://www.agricultura.gov.br/pls/portal/docs/PAGE/MAPA/SERVICOS/USINAS_DESTILARIAS/USINAS_CADASTRADAS/UPS_12-07-2010_0.PDF>. Acesso em: 28 jul. 2010.

CONAB. Companhia Brasileira de Abastecimento. **Safras**: 1º levantamento de safra de cana-de-açúcar: abril 2010. Disponível em: < http://www.conab.gov.br/detalhe.pdf>. Acesso em: 30 jun. 2010.

DIAMOND, J. **Armas, germes e aço**. Tradução Sílvia Costa, Cynthia Cortes, e Paulo Soares. 10. ed. Rio de Janeiro: Record, 2008. 476 p.

EPE. Empresa de Pesquisa Energética. **Análise de conjuntura dos biocombustíveis**: jan. 2009 a mar. 2010. Disponível em: <http://www.epe.gov.br/Petroleo/Paginas/PaineldeBiocombust%C3%ADveis%E2%80%93Boletinsdean% C3%A1lisedeconjuntura.aspx>. Acesso em: 4 ago. 2010.

FIGUEIREDO, P. Breve história da cana-de-açúcar e do papel do Instituto Agronômico no seu estabelecimento no Brasil. In: DINARDO-MIRANDA, L. L.; VASCONCELOS, A. C. M.; LANDELL, M. G. de A. (Ed.). **Cana-de-açúcar**. Campinas: IAC, 2008.

GUIA da Cana-de-açúcar: avanço científico beneficia o país. Brasília, DF: Conselho de Informações sobre Biotecnologia 2009. 20 p.

IBGE. Instituto Brasileiro de Geografia e Estatística. Centro de documentação e disseminação de informações. Estatísticas do século XX. Rio de Janeiro, 2003. 540 p.

IBGE. Instituto Brasileiro de Geografia e Estatística. **Estatísticas históricas do Brasil**: séries econômicas, demográficas e sociais de 1550 a 1988. 2. ed. rev. e atual. Rio de Janeiro: IBGE, 1990. (Séries Estatísticas Retrospectivas, 3).

IBGE. Instituto Brasileiro de Geografia e Estatística. Pesquisa Agrícola Municipal [para os períodos de 2008 a 2010]. Disponível em: <http://www.ibge.gov.br/home/>. Acesso em: 30 jun. 2010.

IPEA. Instituto de Pesquisa da Econômica Aplicada. **Dados de cana-de-açúcar** [de 1940 a 2007]. Disponível em: <www.ipeadata.gov.br>. Acesso em: 30 jun. 2010.

KAUTSKY, K. **A questão agrária**. São Paulo: Proposta, 1980. 325 p.

KUHN, T. **La estructura de las revoluciones científicas**. Tradução Agustín Contín. Madrid: Fondo de Cultura Económica, 1975.

LIBONI, L. B.; TONETO JÚNIOR, R. **A indústria de equipamentos para o setor sucroalcooleiro**. São Paulo, 2010. Trabalho apresentado no I Workshop do Setor Sucroalcooleiro, Ribeirão Preto, 2008. Disponível em: <http://www.observatoriodacana.org/files/Industria%20de%20Equipamentos.pdf>. Acesso em: 27 jul. 2010.

MAIA, M. I. M. R. L. S. **O desenvolvimento da ciência em Thomas Kuhn**. Disponível em: <http://www.consciencia.org/thomas-kuhn-ciencia>. Acesso em: 26 jul. 2010.

NEVES, F.; CONEJERO, M. A. **Estratégias para a cana no Brasil**: um negócio classe mundial. São Paulo: Atlas, 2010. 288 p.

PORTAL DO AGRONEGÓCIO. **Novos tipos de cana racionalizam as atividades agricultura**. <http://www.portaldoagronegocio.com.br/conteudo.php?id=14809>. Acesso em: 2 ago. 2010.

SILVA, J. H. da. **Um perfil da expansão canavieira na Alta Paulista**. Marilia: Unesp, 2008. 20 p.

SIMÕES, J. **P&D em etanol**. Disponível em: <http://ethanolbrasil.blogspot.com>. Acesso em: 4 ago. 2010.

SOUZA, R. C.; CAMARGO, M. E. **Análise e previsão de séries temporais**: os modelos Arima. Ijuí: Sedigraf, 1996.

SZMRECSÁNYI, T.; MOREIRA, E. P. O desenvolvimento da indústria canavieira do Brasil desde a Segunda Guerra Mundial. **Estudos Avançados**, São Paulo, v. 5, n. 11, p. 57-79, 1991.

ÚNICA. União da Indústria da Cana-de-açúcar. **Setor sucroenergético**: mapa da produção. 2010. Disponível em <http://www.unica.com.br/ content/show.asp?cntCode={D6C39D36-69BA-458D-A95C-815C87E4404D}>. Acesso em: 22 jul. 2010.

VERMULM, R. **O setor de bens de capital**. São Paulo: Departamento de Economia-FEA-USP, 1993.

VIOTTI. E. **Indicadores de competitividade em cadeias produtivas**. Brasília, DF: MDIC, 2001.