International Food and Agribusiness Management Review
Volume 17 Issue 2, 2014

Investment Potential for New Sugarcane Plants in Brazil Based on Assessment of Operational Efficiency

Alexandre Pereira Salgado Junior[①a], Fabio Vogelaar Carlucci[b], Carlos Alberto Grespan Bonacim[c], Juliana Chiaretti Novi[d] and Antonio Carlos Pacagnella Junior[e]

[a] *Professor,* [b] *PhD Candidate,* [c] *Professor,* [c] *Professor,* [d] *PhD Candidate, Department of Business Administration.College of Economics, Business Administration, and Accounting of Ribeirão Preto (FEA-RP/USP)–University of São Paulo, Brazil*

[e] *Professor, Department of Operation Management. University Metodista of Piracicaba (UNIMEP), Brazil*

Abstract

The aim of this study is to elaborate on a map of agricultural potential for investing in new sugarcane plants in Brazil. A study of operational efficiency was conducted using Data Envelopment Analysis (DEA) in which it was possible to identify in 2009 the most efficient plants out of a universe of 355. Quantitative analysis suggests a tendency for efficient plants to be large and located in the state of São Paulo. Operational efficiency was proven to depend on the variables of size and location in which the state of São Paulo has a greater concentration of favorable edaphoclimatic conditions for extracting sugarcane with higher sucrose content. An analysis of agricultural potential in the Brazilian territory suggests the installation of new energy plants in regions that present favorable edaphoclimatic conditions and greater efficiency indexes. The states that were proven favorable, in terms of operational efficiency, are Alagoas, Pernambuco and certain regions of Minas Gerais, Paraná and Mato Grosso do Sul.

Keywords: sugarcane; agribusiness; data envelopment analysis (DEA); operational efficiency

[①]Corresponding author: Tel: + 551636020501
Email: A. P. Salgado Junior: asalgado@usp.br
F. V. Carlucci: fabio.vogelaar@fearp.usp.br
C.A.G Bonacim: carlosbonacim@usp.br
J. C. Novi: juliananovi@fearp.usp.br
A. C. Pacagnella Junior: acpjr@.usp.br

Introduction

This study addresses the operational efficiency of sugarcane and ethanol production plants in Brazil during the 2008/2009 harvest using the Data Envelopment Analysis (DEA) technique; case studies are subsequently presented with the aim of achieving an in-depth understanding of the variables that influence this process.

According to The World Bank (2012), Brazil has the seventh largest economy in the world, with a GDP of US$ 2.253 trillion. Brazil is the world leader in coffee, sugarcane and orange production. Its main agricultural products are soybean, meat, sugar/ethanol, coffee, oranges, corn, cassava and tobacco (Pereira, Teixeira and Raszap-Skorbiansky, 2010). Among the crops produced in Brazil today, the sugarcane agroindustry is of greatest importance to the country. The Brazilian Institute of Geography and Statistics – IBGE (2011) states that the 2009/2010 sugarcane harvest represented nearly 15% of Brazil`s total planted acreage. According to Torquato, Martins and Ramos (2009), the factors that drove the growth of sugarcane production in Brazil were crop expansion into new regions of Brazil in conjunction with growing demand and “environmental issues, such as the emission of pollutants caused by fossil fuels,” which are currently high on society’s agenda. Corroborating statistics from the Sugarcane Industry Union – UNICA (2011) back up this claim, by indicating that sugarcane processing between the 2001/2002 and the 2008/2009 harvests increased by 94%, whereas sugar and ethanol production over the same period grew by 62% and 138%, respectively. Sugar and ethanol production in Brazil is a key component of the country`s rural and energy development strategy (Martinelli et al., 2011).

According to Bragato et al. (2008), Brazil`s sugar and alcohol sector drives development with a significant social dimension and is the foundation of the country`s economic sustainability. In support of the above statement, Torquato, Martins and Ramos (2009) point out that production facilities in the sugar and alcohol sectors must seek to achieve greater efficiency in the use of resources employed in production, by adapting to a new production model, which takes into account growing competition and optimization of productivity. In Brazil, the state of São Paulo is of great importance to the sugarcane agroindustry. Today, the state of São Paulo is responsible for half the acreage occupied by Brazil`s sugarcane crop and is responsible for 60% of all sugarcane available for processing. This proves the importance of São Paulo to the sugarcane crop (Martinelli et al., 2011).

Besides the importance of the sugarcane agroindustry to the country, there are opportunities for growth and for greater investment. According to UNICA (2011), in order to manage and balance sector production and demand, private enterprise has tried to create market instruments, such as futures operations, and to develop new opportunities for sugar and ethanol by eliminating protectionist barriers and striving to transform ethanol into an environmental "commodity." Used in the production of sugar and ethanol fuel, sugarcane has been the object of study as a possible solution for today's environmental issues, as mentioned above. Hence, it is important to study the efficiency of plants that process the crop yielding sugar and ethanol and to investigate possible alternatives in order to improve production processes based on decisions aimed at achieving greater efficiency. It also becomes important to undertake studies that explore the variables influencing efficiency with the aim of supporting the decision-making process as it pertains to the choice of sites and technologies for new sugar/ethanol plants.

Considering the importance of this theme, the present study aims to develop an agricultural potential map for investments in new sugar/ethanol plants in Brazil, taking into account their operational efficiency.

Literature Review

According to Goldemberg and Guardabassi (2009), measures are in progress to meet the growing demand for ethanol fuel in Brazil. According to Dias et al (2011), an increase in the planted acreage will be necessary, as will improvements in sugarcane agriculture. Such improvements will be necessary in order to make possible the production of a greater quantity of ethanol per hectare, as well as the development of new technologies and improvements in existing processes, thereby permitting a greater quantity of ethanol to be obtained per ton of sugarcane. It thus becomes necessary to describe the sugar and ethanol production process.

According to Morandin et al. (2011), the conversion of sugarcane into sugar or ethanol consists of a series of physical and chemical processes that take place in seven basic sub-systems. Portions of the production process are common to both sugar and ethanol. The common areas include the planting, cultivation and harvesting of sugarcane, as well as the weighing, sampling and delivery of sugarcane to the production line. After that, the broth is extracted, which represents the raw material for the production of sugar and ethanol. In order to produce sugar, the processes of purification, evaporation, crystallization and centrifugation are implemented through the final production of sugar. Production of ethanol is initiated by fermentation, and then distillation followed by dehydration, ultimately arriving at the final product, ethanol.

Figure 1 shows a simplified flowchart for the basic sugar and ethanol production processes, in which the operations are the same up to the sugarcane broth extraction phase; the extract is later sent to the sugar production process or the ethanol production process. The processes enclosed in dashed lines will be described because of their importance to the results of the present research.

After examining the production process in sugarcane plants, a literature review of some important technologies and processes from the operational efficiency perspective also becomes relevant. According to Romão Junior (2009), chopped sugarcane, from mechanized harvesting, has more surface area to attract impurities. Thus, if the plant washes the chopped sugarcane with water, sugar loss will be around 5%, making this approach unfeasible.

The Sugarcane Technology Center (CTC), in partnership with the Technological Institute for Aeronautics (ITA), developed a technology for dry cleaning sugarcane, which functions by means of a ventilation process capable of eliminating the main impurities present in sugarcane harvested from the field. The sugarcane dry cleaningsystem (SLCS) is an alternative to systems in which sugarcane is washed with water. The straw (plant impurities) and most of the sand and dirt (mineral impurities) are removed. There is no sucrose loss, permitting the process to be used for whole or chopped sugarcane, with return of impurities to the field.

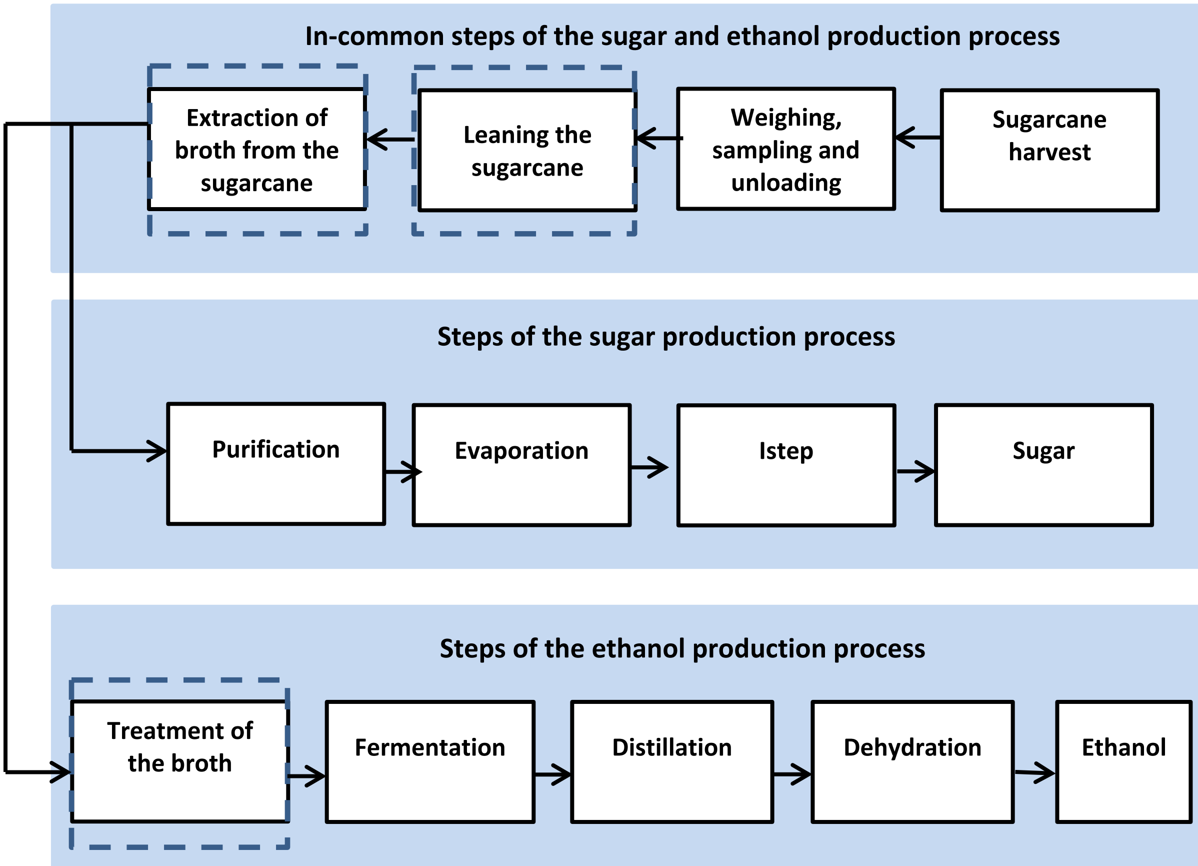

Figure 1. Flow diagram for the basic sugar and ethanol production process
Source. Adapted by Krajnc and Gravic (2009)

Another important step in the sugar and ethanol production process is broth extraction. The frequently used technologies in this process are the diffuser and the grinder. In this step, the plant seeks to extract as much broth as possible with as few impurities as possible. Grinding is a physical extraction process, in which separation occurs as a result of mechanical pressure on the sugar cane during milling. Diffusion requires two steps: separation by reverse osmosis and leaching.

According to Nazato et al. (2011), in the extraction process using the diffuser, installation and maintenance are more economical. The broth is richer in sucrose and partially clarified and has a favorable energy balance. With the grinder, there is no need for high quality raw material. Adaptation to the period between harvests, when sugarcane is scarce, is readily achieved. The grinder leaves an ideal residue for burning due to its low moisture content and the grinding equipment can be expanded, permitting an increase in the quantity of sugarcane ground. Therefore, both technologies have their advantages.

Whereas the diffuser is able to extract between 97.5% and 98.5% of the broth and shows loss of quality when the raw material has low fiber content, the grinder is able to extract 96.5% to 97.5% of the broth and does not demonstrate any sort of extraction difficulty related to raw material quality (Nazato et al. 2011).

Treatment of the broth is another step in the process of broth fermentation or distillation, and is important from the perspective of the equipment used in the production process that allows for greater operational efficiency in the production of ethanol. Use of a broth treatment filter can guarantee greater operational efficiency through preservation of nutrients, vitamins, sugars and phosphates, and mineral salts, which are necessary for yeast metabolism, as well as reduction in contaminants through the elimination of impurities, which reduce efficiency of the machinery during production (Agência de Informação Embrapa 2012). In order to recover the sugar content of the sludge, it is necessary to proceed with the filtration process, that is, separation of the filtered broth from the residue retained by the filter. The broth returns to the production process and the cake, basically comprised of residue removed during decantation, is used in the fields. Therefore, the filter is able to retain impurities contained in the broth with low loss of sucrose content. The capacity to retain solids suspended in the liquid extracted from sugarcane increases from 57%, in the traditional system, to 93% using the filter (REDETEC 2012).

Sugarcane's Edaphoclimatic Aspects

Cesar et al. (1987) state that there are several factors that interfere in sugarcane production and maturation, such as edaphoclimatic interaction, crop management and the sugarcane variety chosen. The aforementioned factors are important to this study because they interfere with sugar and ethanol production. According to Lepsch (1987), knowledge of each soil's characteristics, the so-called edaphic factors, is important in judging the soil's potential productivity.

The initial concept of latosol considered soils whose characteristics were related to intense weathering and leaching and were responsible for low clay activity. Latosols are frequently used with annual crops, perennial crops, pastures and reforestation and are normally located on flat to gently undulating reliefs with declivities rarely greater than 7%, which facilitated the mechanization process. Despite the high potential for agriculture, a portion of the acreage must be set aside as a reserve to protect the environment's biodiversity (Agência de Informação Embrapa 2012).

In loamy soils, according to the Agência de Informação Embrapa (2012), a great deal of diversity is observed in properties relevant to fertility and agricultural use (variable nutrient content, texture, depth, presence or absence of gravel, stones, occurrence in different positions on the landscape). When fertility is high and stones are sparse, the soil is well suited for agriculture. Cambissol is a soil that is poorly developed. Its main characteristics are low depth and high gravel content. Also according to the Agência de Informação Embrapa (2012), purple soil includes soils of great importance to agriculture and with high production potential.

Corroborating this information, Ker (1997) states that purple latosol, commonly called purple soil, has great agricultural potential and is frequently found in the state of São Paulo. According to Delgado et al. (2012), the study of cultivated areas is a fundamental source of information in agricultural and territorial planning, in relation to economic, agrarian, environmental and social issues.

According to Netafim's Agriculture Department (2012), the quality of sugarcane broth is deeply influenced by prevailing climatic conditions during the various sub-periods of crop growth.

Thus, a favorable climate for growing sugarcane may be characterized as a long, hot season with rainfall between 1100 and 1500 mm, showing good distribution - especially, with the highest incidence during the growth months - as well as a reasonably dry and sunny season. Figure 2 shows the locations of Brazil's sugarcane industry.

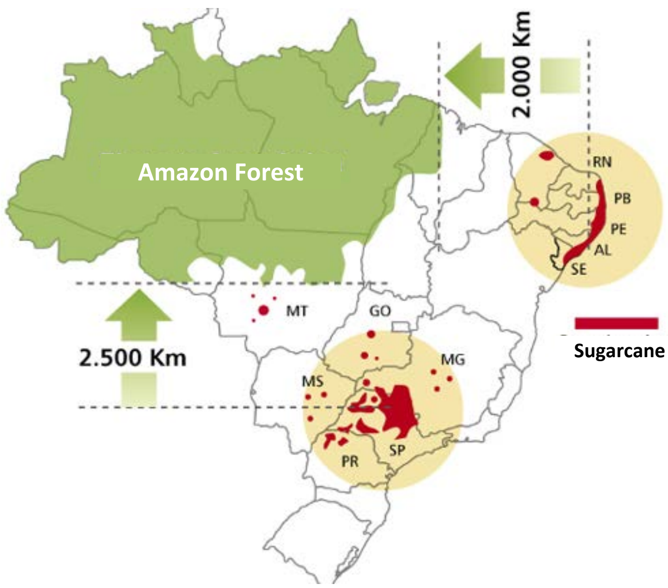

Figure 2. Sugarcane industry in Brazil
Source. UNICA (2011)

Chart 1 provides a summary of the main types of soil and climate in Brazilian territory in the sugarcane producing states.

Chart 1. Classification of edaphoclimatic factors in certain states in Brazil

State	Edaphoclimatic Conditions	
	Soil	*Climate*
São Paulo	Predominantly latosol, podzol and purple latosol.	Predominantly tropical
Minas Gerais	Predominantly latosol, podzol and purple latosol. Cambisol, lithic	Tropical
Paraná	Predominantly Cambisol and lithic Latosol, podzol and purple latosol.	Predominantly wet sub-tropical
Mato Grosso do Sul	Predominantly alluvial hydromorphic quartz sands.	Predominantly tropical
Goiás	Predominantly latosol, podzol and purple latosol.Cambisol, lithic	Tropical
Mato Grosso	Predominantly alluvial hydromorphic quartz sands. Leached soils under the forest.	Tropical and wet equatorial.
Alagoas	Predominantly non-calcic brown.Latosol, podzol.	Predominantly tropical.Tropical, semi-arid.
Pernambuco	Predominantly non-calcic brown.Latosol, podzol.	Predominantly tropical, semi-arid.Tropical

It is estimated that the sugarcane crop occupies 8 million hectares of land in Brazil, distributed in a heterogeneous manner over several states, with 60% in the state of São Paulo (Novaes et al. 2011).

Conceptual Framework

The Data Envelopment Analysis (DEA) technique was used to evaluate the operating efficiency of sugar/ethanol plants. All sugar/ethanol plants for which data are available in the Sugarcane Yearbook for the 2008/2009 harvest and that are the object of study in this paper were considered Decision Making Units (DMUs) to be compared in terms of operational efficiency.

Farrell's (1957) efficiency concepts comprise the basis for the theory of efficiency in the DEA model. The concepts were idealized by Charnes, Cooper and Rhodes (1978), who, using mathematical models, developed a technique with which it is possible to establish optimal standards of efficiency based on the relationship between outputs and inputs using linear programming.

According to Senra et al. (2007), the DEA CCR (Charnes, Cooper and Rhodes) model maximizes the quotient between the linear combination of the outputs and the linear combination of the inputs, with the restriction that for any DMU this quotient cannot be greater than 1. This problem of fractional programming, in some mathematical treatments, may be linearized and translated into the Linear-Programming Problem (LPP), in which h_0 is the efficiency of DMU_0 under analysis; x_{i0} and y_{i0} are the inputs and outputs of DMU_0; v_i and u_j are the weights calculated by the model for inputs and outputs, respectively.

$$\max \ h_o = \sum_{j=1}^{m} u_j y_{jo}$$
$$\text{subject to}$$
$$\sum_{i=1}^{n} v_i x_{io} = 1$$
$$\sum_{r=1}^{m} u_j y_{jo} - \sum_{i=1}^{n} v_i x_{ik} \leq 0$$
$$k = 1, \ldots, s$$
$$u_j, v_i \geq 0 \qquad \forall i, j$$

According to Cooper, Seiford and Tone (2007), based on the database, the efficiency of each DMU is evaluated and thus n optimizations are carried out, one for each DMU evaluated in the DEA model. In this way, an attempt is made to optimize the following equation for each DMU:

$$\frac{output}{input}$$

When multiple inputs and multiple outputs are used, the following relation is maximized:

$$\frac{output_1 + output_2 + \ldots + output_s}{input_1 + input_2 + \ldots + input_p}$$

Thus, for n DMUs, the following fractional programming is obtained:

$$\text{Max } \theta(u, v) = \frac{u_1 y_1 + u_2 y_2 + \ldots + u_s y_s}{v_1 x_1 + v_2 x_2 + \ldots + v_p x_p}$$

subject to

$$\frac{u_1 y_{1j} + \ldots + u_s y_{sj}}{v_1 x_{1j} + \ldots + v_p x_{pj}} \leq 1$$

$$u_1, u_2, \ldots, u_s \geq 0 \quad (\textit{inputs})$$

$$v_1, v_2, \ldots, v_p \geq 0 \quad (\textit{outputs})$$

in which, an attempt is made to maximize the DMU_0 result, where the optimal result corresponds to a value of θ equal to 1, in which u and v represent the weights of the input and output variables, respectively, and y and x represent the values for each input and output variable. It is necessary to restrict all model variables to non-negative values.

Since this is a linear programming technique, it is necessary to transform the fractional programming model into a linear programming model.

$$\text{Max } \theta(\mu, v) = \mu_1 y_1 + \mu_2 y_2 + \ldots + \mu_s y_s$$

subject to

$$v_1 x_1 + \ldots + v_m x_m = 1$$

$$\mu_1 y_{1j} + \ldots + \mu_s y_{sj} \leq v_1 x_{1j} + \ldots + v_p x_{pj}$$

$$v_1, v_2, \ldots, v_m \geq 0$$

$$\mu_1, \mu_2, \ldots, \quad \mu_s \geq 0$$

Methodological Aspects

This study's research method is divided into two parts, one quantitative and the other qualitative. The first phase of the research employs a quantitative approach by applying the Data Envelopment Analysis (DEA) technique to categorize and classify the universe of plants studied in relation to operational efficiency. The second phase is qualitative, in which a multiple case study is performed at plants, and interviews are conducted with specialists; the results are described using content analysis, aimed at an in-depth analysis of the data obtained in the first phase.

The DEA technique was implemented using Frontier Analyst software, manufactured by Banxia Software®. Use of the output-oriented BCC model was considered the most appropriate, by virtue of two main factors: the first concerns the fact that it is not possible to establish a proportional relationship between inputs and outputs when the productive operation of a sugarcane plant is considered; the second, related to the output orientation of the model, pertains to the growing number of new sugarcane plants in Brazil, which leads to resource scarcity, considering that efficient use can increase the level of competitiveness of these organizations and the quantity of sugar and ethanol produced.

The database used in this study was organized based on the sugarcane harvest of 2008/2009 and encompasses the total quantity, in tons, of sugarcane ground by Brazilian plants and the total quantity of sugar and ethanol produced, in tons. The DMUs are the sugarcane plants, and sugar and ethanol producers located in Brazil, according to the database.

Chart 2 shows the variables considered in this study, together with their classification in terms of input and output and their technical definition.

Chart 2. Classification of variables

Variables	**Classification**	**Definition**
Grinding (tons)	*Input*	Total amount of sugarcane, in tons, ground for the production of sugar and/or ethanol by the plant.
Sugar (tons)	*Output*	Total amount of sugar, in tons, produced by the plant.
Ethanol (tons)	*Output*	Total amount of ethanol, in m^3, produced by the plant.

Three strata were constructed for analysis of plant size according to the categories used by UNICA (2011), in which large plants are those with a grinding capacity greater than 2.5 million tons per harvest; medium plants are those with a grinding capacity of 1.0 to 2.5 million tons per harvest; and small plants are those with a grinding capacity of less than 1.0 million tons per harvest. Therefore, three basic, operational variables were used for a sugarcane plant. This study did not consider financial variables.

Then, hypothesis testing was undertaken to determine whether the population of efficient plants differs in relative terms from the population of plants as a whole with respect to the size and location variables. The statistical software used to analyze the data and generate the results is the Statistical Package for Social Sciences® (SPSS), version 18.0.

Taking into account the non-normal distribution of the input variable studied, after conducting the non-parametric KS test shown in Table 1, the binomial non-parametric test of proportions was used to test the influence of the location variable on the operational efficiency of plants and the non-parametric chi-squared test of proportions, to test the influence of the size variable.

Table 1. KS Test for distribution normality

		Grinding Variable
N	Mean	355
Normal Parameters	Std.Deviation	1583988
	Absolute	1258520
Most Extreme	Positive	,134
Differences	Negative	-,108
Kolmogorov-Smirnov Z		2,519
Asymp.Sig.(2-tailed)		,000

In the statistical tests run, the null and alternative hypotheses are as follows:

(1) Chi-squared test for the size variable:
H_0: Among the plants classified as efficient, the proportion of plants by size is the same as in the entire population of plants in Brazil.

H_1: The proportion is different.

(2) Binomial test for the location variable:
H_0: Among the plants classified as efficient, the proportion of plants in the State of São Paulo is the same as in the entire population of plants in Brazil.
H_1: The proportion is different.

The second phase of the study, qualitative in nature, includes the performance of a multiple case study at sugarcane plants through technical visits and by conducting semi-structured interviews with managers of plant agricultural and industrial departments, seeking a better understanding of the phenomenon.

To produce an overview of the study design, existing literature was used together with information obtained from three interviews conducted with specialists in the field. The interviews conducted with sugar and alcohol sector specialists were semi-structured with the objective of increasing the degree of familiarity with the object of study and to make adjustments in the variables addressed throughout the multiple case study.

It was thus possible to develop a logical case study model, as proposed by Yin (2010), which seeks to achieve the protocol objectives of the multiple case studies, as shown in Figure 3.

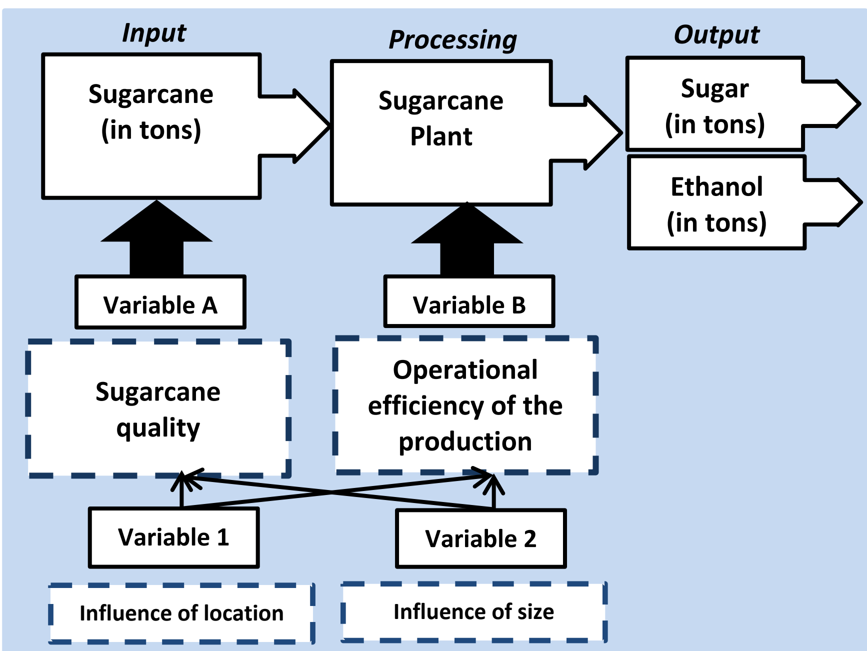

Figure 3. Logical model of the research protocol, adapted from Yin (2010)

The qualitative phase of the study had as its objective to determine how the size and location variables relate to the sugarcane quality variables and operational efficiency of the production process. The theoretical reference, along with the interviews conducted among the specialists, enabled the development of a logical model of the research protocol in order to confirm, by means of the multiple case study, the results obtained in the quantitative phase of the present study. According to Dinardo et al. (2011), among the main parameters of sugarcane quality is the

sucrose content. Thus, in this study, quality will be considered to be the apparent sucrose content in the cane.
The multiple case study was conducted with four representative sugarcane plants, chosen on the basis of the data obtained in the quantitative phase, which are presented in Chart 3.

Chart 3. Information from the multiple case study

Location		Size	Classification	Interviewed
Plant A	SP	Large	Efficient	Agriculture quality coordinator
Plant B	AL	Small	Efficient	Supervisor of agriculture controls
Plant C	SP	Medium	Inefficient	Industrial manager, production planning and control supervisor, work safety coordinator, agriculture management coordinator.
Plant D	SP	Medium	Inefficient	Industrial manager, agriculture manager, agriculture quality supervisor.

Content analysis was used as a research tool to evaluate the results of the semi-structured interviews conducted at the sugarcane plants in the multiple case studies during the qualitative phase of the research.

Results and Discussion

The results of the descriptive analysis allowed a detailed analysis of the input and output variables of the DEA model used in this study. The relation between the total amount of sugarcane available for processing and the total production of sugar and ethanol was analyzed for the set of sugarcane plants studied in connection with the 2008/2009 harvest. The plants were then evaluated for their operational efficiency. Eleven of the 355 plants analyzed in this study were classified as efficient. This represents approximately 3% of the total population of plants.

Table 2 shows the input and output values (in tons) for the eleven efficient plants according to the DEA technique used. The grinding figures represent the total volume of processed sugarcane, which constitutes the model's input variable. On the other hand, the sugar and ethanol values represent the values produced throughout the 2008/2009 harvest and constitute the model's two output variables.

It is possible to observe that eight of the eleven plants considered efficient are located in the State of São Paulo, whereas, in relation to size, there are five large, two medium and four small plants in the group of efficient plants. According to Salgado Junior, Bonacim and Pacagnella Junior (2009), efficiency in DEA analyses is independent of the size of the plant, because it is the proportionality between the inputs and outputs in the model that make the DMU efficient or not. After completion of the hypothesis testing, it was possible to determine whether this group of plants can be considered significantly different from the general plant population. However, it is important to note that efficiency in DEA is always relative, taking into account the DMUs that belong to the group of plants analyzed in this study.

Table 2. Efficient plants

Sugar/Ethanol Plant	State	Size	Grinding Variable (tons)	Sugar (tons)	Ethanol (m^3)	*Score*
Usina da Barra S/A Açúcar e Álcool da Barra	SP	Large	7,378,408	499,772	315,804	100.00
Usina da Barra S/A Açúcar e Álcool de Bonfim	SP	Large	4,785,973	371,412	193,029	100.00
Açúcar Guarani S/A	SP	Large	4,436,982	459,022	78,592	100.00
Andrade Açúcar e Álcool S/A	SP	Large	3,187,694	183,794	200,881	100.00
Usina de Açúcar Santa Terezinha Ltda.Ivaté	PR	Medium	2,001,450	222,151	46,061	100.00
Aralco S/A Indústria e Comércio	SP	Small	833,436	106,57333	0	100.00
Companhia Brasileira de Açúcar e Álcool Filial ICEM	SP	Small	405,029	59,212	0	100.00
Usina São Martinho S/A	SP	Large	8,004,221	445,903	411,991	100.00
Usina Santa Adélia S/A Filial Usina Interlagos	SP	Medium	2,151,099	0	184,880	100.00
Laginha Agro Industrial S/A Matriz	AL	Small	630,349	0	72,752	100.00
Companhia Usina Bulhões	PE	Small	72,612	0	9,653	100.00

Regarding the location variable, Table 3 shows on a state-by-state basis the frequency of efficient plants compared to the frequency obtained for the entire population.

Table 3. Frequencies by location

State	Efficient Plants	Total Population
São Paulo	8 (72.7%)	170 (47.9%)
Minas Gerais	-	32 (9%)
Paraná	1 (9.09%)	28 (7.88%)
Mato Grosso do Sul	-	14 (3.94%)
Goiás	-	28 (7.88%)
Mato Grosso	-	11 (3.1%)
Alagoas	1 (9.09%)	24 (6.76%)
Pernambuco	1 (9.09%)	23 (6.48%)
Outros estados somados	-	25 (7,04%)
Total	**11 (100,00%)**	**355 (100,00%)**

Among the efficient sugarcane plants operating in Brazil, a significant number of them are located in the state of São Paulo. Although there are many inefficient plants in the state of São Paulo, the proportion of plants in the state of São Paulo in the efficient group is greater (73%) than that of the total population of plants in Brazil (47.9%).

Table 4 shows the statistical analysis of the location variable.

Table 4. Statistical test for location

	Category	Location	Number Observed	Test Prop.	Exact Sig. (1-tailed)	Sig.
Location	Group 1	State of São Paulo	8	.727	.479	.090
	Group 2	Other states	3	.273		
	Total		**11**	**1.00**		

Besides the location variable, another important variable in the study is the size of the sugarcane plants, when compared to their efficiency. The chi-squared test was used to test for differences in proportions in relation to this variable. Table 5 shows the observed frequencies for the group of efficient plants and for the total population in relation to size.

Table 5. Frequencies by size

	Efficient plants	Total Population
Large Plants	5 (45.5%)	60 (16.9%)
Medium Plants	2 (18.2%)	163 (45.9%)
Small Plants	4 (36.3%)	132 (37.2%)
Total	**11 (100.0%)**	**355 (100.0%)**

Table 6 tests the null hypothesis (H_0) that the frequencies observed in the group of efficient plants sampled are equal to the frequencies observed in the total population, that is, the group of all plants studied.

Table 6. Chi-squared test

	Observed N	Expected N	Residual
Large Plants	5	1.9	3.1
Medium Plants	2	5.1	-3.1
Small Plants	4	4.1	-.1
Total	**11**		

Considering that 16.9% of the total population consisted of large plants, 45.9% medium plants and 37.2% small plants, the values expected for the sample of 11 plants were 1.90 (16.9%) large plants, 5.10 (45%) medium plants and 4.10 (37.2%) small plants. However, the actual values observed in the group of efficient plants were 5 (45.5%) large plants, 2 (18.2%) medium plants and 4 (36.3%) small plants. Table 7 shows the statistical analysis of the size variable.

Table 7. Statistical test for size

	Size
Chi-Square	7.149
DF	2
Asymp.Sig.	.028

It is possible to state that, in relation to the size variable, the sample is different from the population, that is, at a significance level of 95%, the null hypothesis (H_0) can be rejected, which means that the proportions observed for efficient plants are different from the proportions found for the total population of plants with respect to size.

The size variable, as well as the location variable, therefore exerts some influence on the capacity of plants to operate with greater efficiency. In order to verify the results of the statistical analyses, multiple case studies were conducted at the various sugarcane plants.

The results of the qualitative phase of the present study are shown below. First, an attempt was made to ascertain the factors that enable sugarcane plants to realize greater operational efficiency and then to analyze the possible impact of the size and location variables on such factors. Based on the interviews conducted with the specialists, it was possible to obtain evidence that operational efficiency is related to higher quality sugarcane, which allows more juice to be extracted, thus resulting in greater sugar and ethanol production. Operational efficiency may also be related to the use of technologically more sophisticated machinery and equipment on the production line, permitting greater productivity.

Chart 4 shows the main results obtained in the multiple case study in relation to sugarcane quality, which is influenced by the weather and soil conditions (Variable A) and the operational efficiency of the production process (Variable B) for the four plants studied.

Based on the interviews conducted, especially in the multiple case studies at plants A, C and D, it was possible to make the assumption that, by virtue of high fixed costs inherent to sugarcane plant installations, managers seek to use the maximum installed production capacity because an increase in the volume processed by the plant means a higher financial gain. It was noted that some equipment or technologies that the plants have can provide greater operational efficiency.

However, based on the interviews with specialists and the multiple case studies, especially at plants C and D, evidence was obtained that it is more cost-effective to increase the quantity of processed sugarcane than to increase sugar and ethanol productivity by the plant. Therefore, the study conducted suggests that initially there should be greater investment in increasing sugarcane grinding capacity; that is, an increase in the volume of processed sugarcane and subsequent investment in equipment and technologies that permit increased operational efficiency. Thus, investments in technology would be an alternative for plants that would no longer have the means to increase grinding capacity. Consequently, these would be large plants.

This result corroborates the conclusions of Romão Junior (2009) that some equipment represents a big investment with high implementation costs and, for this reason, bears a relationship to the size and operational characteristics of the plants.

Chart 4. Results found in the multiple case study

	Location	Size	Classification	*Score*	Variable A – Weather and Soil Conditions	Variable B – Operating Efficiency of the Production Process
Plant A	SP	Large	Efficient	100.00	Tropical climate	Predominantly mechanized harvest, use of a grinder, SLCS, use of continuous fermentation, molecular sieve for anhydrous recovery, use of a filter in treating the broth.
Plant B	AL	Small	Efficient	100.00	Wet, coastal climate/ reddish-yellow and clay latosols	Manual harvesting, use of a grinder, continuous fermentation, use of filters for treating broth and evaporators.
Plant C	SP	Medium	Inefficient	91.27	Tropical climate; acrid latosols	Predominantly mechanized harvest, use of a grinder, sugarcane cleaned predominantly with water, does not use other equipment in production.
Plant D	SP	Medium	Inefficient	87.77	Tropical climate; acrid latosols	Predominantly mechanized harvest, use of a grinder, sugarcane not cleaned, filter used for treating broth, fermentation by batches

The main equipment or technologies that permit gains in efficiency, based on the interviews, were the dry sugarcane cleaning system (SLCS) and the filter for treating the broth. In relation to Variable 2, regarding the operational efficiency of the production process, combustion of sugarcane is a factor that proved relevant to the study, since it can eliminate sugarcane straw, which hampers broth extraction. Thus, the method for harvesting sugarcane in the field has consequences for the quantity of straw (plant impurity) and soil (mineral impurity) in the sugarcane at the moment it enters the production line, which could influence broth extraction.

However, the sugarcane cleaning process precedes broth extraction and tends to facilitate its extraction using grinders and / or diffusers. During the sugarcane cleaning process, it is possible to clean the system with water or to employ the SLCS, or dry sugarcane cleaning system. This reduces the silica and removes sugarcane straw, which, in turn, contributes to greater sugarcane extraction capacity and avoids waste. Based on the cases studied, this step proved relevant to the extent that it is able to influence the quantity of impurities impinging on the production process.

Corroborating the study by Ribeiro (2008), there is evidence that manual harvesting is less frequent in the state of São Paulo, where sugarcane is harvested with harvesters that expel some of the straw without the need for burning. Thus, the SLCS proved to be an important technology, capable of permitting sugarcane to enter the production line without the interference of plant and mineral impurities that could hamper grinder or diffuser action. In this respect, scale was identified as an important factor in relation to the operational efficiency of the production

process, since greater scale justifies investment in equipment that takes better advantage of the tons of sugarcane that enter the production line.
Based on a literature review followed by interviews with specialists and the multiple case studies conducted at the plants, it was possible to obtain evidence that the soil and climate, which together comprise the edaphoclimatic factors, are important and impactful determinants of sugarcane quality. Cesar et al. (1987) support these results, stating that there are several factors that interfere in sugarcane production and maturation, such as edaphoclimatic interaction, crop management and the sugarcane variety chosen. Crop management and genetic variety, however, are aspects of the production process that seek to take utmost advantage of the production environment's agricultural potential, that is, to enable the full use of the soil's production potential.

Plant A and plant B were used as evidence of the significance of climatic and soil factors, since these two plants, classified as efficient in the quantitative phase of the study, are located in regions with favorable production environments. Corroborating the statements by Smeets et al. (2009), Torquatro, Martins and Ramos (2009) and Martinelli et al. (2011), there is evidence that the state of São Paulo is located in a region with favorable edaphoclimatic factors for the sugarcane crop.

There is a concentration of plants located in the northeast region of the State of São Paulo that coincides with the location of red earth, or red latosol (LR). According to the Agência de Informação Embrapa (2012), red earth is one of the soils of great agricultural importance and high production potential, responds well to fertilizer and soil correction and is well suited for crops and other agropastoral uses. According to Ker (1997), the favorable conditions for agriculture in red latosol areas (Rio Grandense plateau, northern Paraná, parts of São Paulo, especially Ribeirão Preto, southeastern Goiás, Dourado and Tangará da Serra) appear to confirm the high agricultural potential of this soil type, because of its natural fertility, ease of and response to fertility correction when needed, and ample potential for mechanization and irrigation in some locations.

Corroborating such claims, according to Sobiologia (2012), red earth is a soil that stands out due to its fertility and occurs in the states of Rio Grande do Sul, Santa Catarina, Paraná, São Paulo and Mato Grosso do Sul.

Plant A is located in a region where the predominant soil can be classified as red latosol, or simply red earth. Plant B, on the other hand, is located in a region whose soil is classified as reddish-yellow latosol. According to Ker (1997), reddish-yellow latosol is the most abundant latosol in Brazil with the widest geographic distribution. Latosols vary considerably in their natural fertility and occur in areas ranging from flat relief (plateaus) to mountainous. Plant A and plant B are classified as efficient.

Chart 5 reproduces the final portion of Yin's (2010) case study in which triangulation of the various lines of evidence obtained in the present study converges to the results presented in Chart 5. The authors who addressed each of these factors, relating them to efficiency in the plants, are listed followed by the plants that, on the basis of the multiple case study, made possible an analysis of the influence of each factor on operational efficiency and, finally, the interview with the specialist that provided further evidence pertaining to the results obtained in the study.

Chart 5. Triangulation of results found

Variables		Factors	Literature Review	Case Study	Specialists
Operational efficiency	Sugarcane quality	Soil	Smeets et al.(2008); Cesar et al.(1987); Lepsch (1987); Maule, Mazza and Martha-Junior (2001); Staut (2012); Embrapa (2012).	Plants A, B	Owner of an input organization for planting sugarcane.
		Climate	Smeets et al.(2008); Cesar et al.(1987); Maule, Mazza and Martha-Junior (2001); Netafim's Agriculture Department (2012).	Plants A, B	Owner of an input organization for planting sugarcane.
	Production process	Dry cleaning the sugarcane	Sermatec (2012); Empral (2012); Romão Junior (2009).	Plants A, C, D	Prof.Dr.UNESP Jaboticabal.
		Filter for cleaning broth	Agência de Informação Embrapa (2012); REDETEC (2012).	Plants A, C, D	Prof.Dr.UNESP Jaboticabal.

Therefore, based on multiple sources of evidence used in this study, there are indications that production environments favorable to sugarcane extraction with higher sucrose content are more common in the state of São Paulo, making gains in operational efficiency possible. There is also evidence that the large plants have greater motivation to invest in equipment and technologies that permit gains in operational efficiency within the sugar and ethanol production process, such as SLCS and the broth treatment filter.

However, it is important to observe that there are plants located in the state of São Paulo that were classified as inefficient. Although this state has regions with edaphoclimatic factors that favor the sugarcane crop, the state of São Paulo also has regions with less favorable production environments, as seen in plant D. Likewise, ripe conditions for the sugarcane crop can also be found in other states, as seen in plant B. Thus, although favorable edaphoclimatic conditions can be found in the state of São Paulo with greater frequency, the same conditions can also be found in other states.

According to Torquatro (2006), new investments in Brazil are on the rise in the Midwest, especially in the states of Mato Grosso do Sul, Mato Grosso and Goiás. In southern Brazil, Paraná is already the second largest producer of sugarcane in the country, trailing only São Paulo. The new tendency to invest in other regions occurs mainly by virtue of high startup costs in the southeast. Goiás is one of the states showing the most growth in terms of sugarcane volume in recent years, according to the IBGE (2011). The occupation of new areas along the border and the reduction in production costs have become the basis for growth in agricultural production in Goiás (Bezerra and Cleps Jr 2004).

Table 8 shows an analysis of efficiency scores based on application of the DEA technique to plants located in the main sugarcane producing states in Brazil.

Table 8. Descriptive analysis of efficiency scores by state

States	No. of plants	Average	Standard deviation	Maximum	Minimum
São Paulo	170	85.20%	10.05%	100%	56.09%
Minas Gerais	32	79.74%	11.35%	98.57%	50.48%
Paraná	28	79.29%	10.66%	100%	61.88%
Mato Grosso do Sul	14	79.43%	10.13%	95.99%	65.57%
Goiás	28	73.84%	11.35%	93.14%	41%
Mato Grosso	11	77.37%	15.28%	94.82%	44.83%
Alagoas	24	82.18%	7.64%	100%	67.38%
Pernambuco	23	79.56%	11.26%	100%	51.47%

Of the 355 existing plants in Brazil, according for the sugarcane yearbook, during the 2008/2009 harvest, 327 plants are located within the territorial limits of the states listed in Table 8, which corresponds to 92.11% of all plants in Brazil.

The state of Alagoas has the second highest average among all states analyzed, at 82.18%, and the lowest standard deviation.The state has reddish-yellow latosols, which, according to Ker (1997), is the most abundant latosol in Brazil with the most widespread geographic distribution. Latosols show considerable variability in their natural fertility and are found in areas that vary from flat relief to mountainous.Although the state of Pernambuco has similar edaphoclimatic conditions, it has an average efficiency of 79.56% and standard deviation of 11.26%. The state of Goiás has the lowest average efficiency rating among the states listed, and a standard deviation of 11.35%. This state has no efficient plants, according to the quantitative analysis developed in the present study. The states of Minas Gerais, Mato Grosso and Mato Grosso do Sul show similar results. One possible factor that could explain the results obtained is the wide variety of different soil types. Mato Grosso still has a slightly lower average value and the biggest standard deviation among those analyzed, at 15.28%. There was a plant in Paraná classified as efficient with an average score of 79.29% and a standard deviation of 10.66%. The state of São Paulo has the highest average efficiency rating, at 85.20%, with a standard deviation of 10.05% and is also the state with the largest number of plants classified as efficient.

Therefore, as seen in plant B, installation in a region with favorable edaphoclimatic factors, together with use of technologies that make gains in efficiency possible, permits maximization of productivity from an operational perspective. The state of Alagoas thus proved to be propitious for the installation of sugar/ethanol plants.

The state of Goiás, on the other hand, despite recent tendencies to increase the quantity of sugarcane processed, does not have a big yield in terms of production. However, it represents a state with potential because it has favorable climatic conditions and specific regions with favorable soil, including red latosol. Thus, it is up to the investor to develop a sugar/ethanol plant capable of developing quality sugarcane and to reap the benefits of this factor through the proper use of technology.

Therefore, it is not enough to simply install sugar/ethanol plants in regions with favorable edaphoclimatic factors. In order to obtain maximum operational efficiency, it is necessary to have a combination of quality sugarcane, along with use of technologies and equipment that enable the optimal use of this raw material for the production of sugar and ethanol.

This made it possible to create Chart 6 (See Appendix), which presents the major observed characteristics of various states in Brazil, from which it was possible to map the sugarcane plants based on their operational efficiency, taking into consideration the agricultural potential of the different states.

Conclusions

Based on the evidence collected in this study, it is possible to make assumptions leading to the conclusion that in the group of efficient plants, there is a higher concentration of plants located in the state of São Paulo in terms of the location variable and a higher concentration of plants whose size is classified as large in terms of the size variable.

With regard to the location variable, the results obtained suggest that, in the state of São Paulo, the soil and climate, that is, the predominant edaphoclimatic factors, contribute to sugarcane of better quality, with a higher level of sucrose, thus permitting greater operational efficiency and, consequently, greater production of sugar and ethanol from the same volume of sugarcane.

It is important to note that, although edaphoclimatic factors predominate in São Paulo, which explains the higher proportion of efficient plants in the state, these factors can be found, in lower proportions, in other states in Brazil. This explains the existence of plants outside the state of São Paulo, classified as efficient, as in the case of plant B,, which is located in the state of Alagoas, in a region with favorable edaphoclimatic factors for growing sugarcane.

Thus, the installation of new sugar/ethanol plants is justified in regions of Brazil that have favorable edaphoclimatic conditions but lower production costs. States that proved to be potentially favorable for the sugarcane crop strictly from the perspective of the operational efficiency of sugar/ethanol plants were Alagoas, Pernambuco and specific regions of Minas Gerais, Paraná and Mato Grosso do Sul, which have favorable edaphoclimatic conditions. The state of Goiás proved to have the lowest average efficiency among the most important sugarcane producing states in Brazil, but has high agricultural potential, especially by virtue of the favorable climatic conditions and the existence of regions that have favorable soils for growing sugarcane. However, investments in technology should be made in the interest of seeking increases in efficiency.

In relation to the size variable, there are indications that large plants have greater motivation to invest in technological equipment that allows for a more efficient production process. Two technologies that showed evidence of exerting an important influence on operational efficiency were SLCS and the broth treatment filter. Conducting SLCS and using filtration to treat broth are technologies that could provide greater operational efficiency and tend to be more frequently used in plants that operate on a large scale, since they are unable to invest in an increase in factory capacity owing to the fact that they are already at the limit of their production capacity.

Therefore, investment in technologies and equipment providing efficiency gain in the total quantity of sugar and ethanol produced is fundamental in order to maximize operational efficiency, as well as to take full advantage of edaphoclimatic factors.

Acknowledgement

This research was supported by the National Counsel of Technological and Scientific Development (CNPq).

References

Agência de Informação Embrapa. 2014. http://www.agencia.cnptia.embrapa.br [accessed February 20, 2014].

Bezerra, L. M. C., and J. Cleps Jr. 2004. O desenvolvimento agrícola da região centro-oeste e as transformações no espaço agrário do estado de Goiás. *Caminhos de Georgrafia* 2: 29-49.

Bragato, I. R., E. S. Siqueira, G. Graziano, and E. E. Spers. 2008. Produção de açúcar e álcool vs. responsabilidade social corporativa: as ações desenvolvidas pelas usinas de cana-de-açúcar frente às externalidades negativas. *Revista Gestão e Produção* 15 (1): 89-100.

Cesar, M. A. A., A. A. Delgado, A. P. de Camargo, B. M. A. Bissoli, and F. C. Silva. 1987. Capacidade de fosfatos naturais e artificiais em elevar o teor de fósforo no caldo de cana-de-açúcar (cana-planta), visando o processo industrial. *STAB: Açúcar, Álcool e Subprodutos* 6:32-38.

Charnes, A., W. W. Cooper, and E. Rhodes. 1978. Measuring the efficiency of decision-making units. *European Journal of Operational Research* 2 (3): 429-444.

Cooper, W. W., L. M. Seiford, and K. Tone. 2007. *Data envelopment analysis: a comprehensive text with models, applications, references and DEA-solver software*. New York: Springer Science.

Delgado, R. C., G. C. Sediyama, M. H. Costa, V. P. Soares, and R. G. Andrade. 2012. Classificação espectral de área plantada com a cultura da cana-de-açúcar por meio da árvore de decisão. *Engenharia Agrícola* 32 (2).

Dinardo, V., H. F. Silva Neto, L. C. Tasso Junior, F. Camilotti, and M. O. Marques. 2011. Avaliação da pol em cana-de-açúcar com ciclo de maturação em início de safra. *Ciência & Tecnologia* 3.

EMPRAL. http://www.empral.com.br/ [accessed August 18, 2012].

Ensinas, A. V., S. A. Nebra, M. A. Lozano, and L. M. Serra. 2007. Analysis of process steam demand reduction and electricity generation in sugar and ethanol production from sugarcane. *Energy Conversion and Management* 48: 2978-2987.

Farrell, M. J. 1957. The measurement of productive efficiency. *Journal of the Royal Statistical Society* 120 (3): 253-290.

Goldemberg, J., and P. Guardabassi. 2008. The sustainability of ethanol production from sugarcane. Energy Policy 36: 2086-2097.

Instituto Brasileiro de Geografia e Estatística (IBGE). http://www.ibge.gov.br [accessed November 30, 2011].

Ker, J. C. 1997. Latossolos do Brasil: uma revisão. *Genomos* 5 (1): 17-40.

Krajnc, D., and P. Glavic. 2009. Assessment of different strategies for the co-production of bioethanol and beet sugar. *Chemical Engineering Research and Design* 87: 1217-1231.

Lepsch, I. F. 1987. Influência dos fatores edáficos na produção. In *Ecofisiologia da produção,* Castro, P.R.C., S. O. Ferreira, S.O., and T. Yamada, 83-98. Piracicaba: Associação Brasileira para Pesquisa da Potassa e do Fosfato.

Martinelli, L. A., R. Garrett, S. Ferraz, and R. Naylor. 2011. Sugar and ethanol production as a rural development strategy in Brazil: evidence from the state of Sao Paulo. *Agricultural Systems* 104: 419-428.

Maule, R. F., J. A. Mazza, and G. B. Martha Junior. 2001. Produtividade agrícola de cultivares de cana-de-açúcar em diferentes solos e épocas de colheita. *Scientia Agrícola* 58: 295-301.

Morandin, M., A. Toffolo, A. Lazzaretto, F. Maréchal, A. V. Ensinas, and S. A. Nebra. 2011. Synthesis and parameter optimization of a combined sugar and ethanol production process integrated with a CHP system. *Energy* 36: 3675-3690.

Nazato, C., D. F. C. Silva, S. C. U. Ferraz, and M. N. C. Harder. 2011. Moenda x Difusor: diferentes pontos de vista sobre o assunto. *Bioenergia em revista* 1: 129-139.

Netafim´s Agriculture Departament. http://www.sugarcanecrops.com/p/soil_requirement/ [accessed August 18, 2012].

Novaes, M. R. de, B. Rudorff, A. M. de Almeida, and D. A. de Aguiar. 2011. Análise espacial da redução da queima na colheita da cana-de-açúcar: perspectivas futuras ao cumprimento do protocolo agroambiental. *Engenharia Agrícola* 31 (3).

Pereira, M. W. G., E. C. Teixeira, and S. Raszap-Skorbiansky. 2010. Impacts of the Doha Round on Brazilian, Chinese and Indian agribusiness. *China Economic Review* 21: 256-271.

Rede de Tecnologia e Inovação do Rio de Janeiro (REDETEC). http://www.redetec.org.br/inventabrasil/vacpres.htm [accessed August 18, 2012].

Ribeiro, H. 2008. Queimadas de cana: efeitos à saúde respiratória. *Revista Saúde Pública* 42 (2): 370-376.

Romão Junior, R. A. 2009. 165 f. Análise da viabilidade do aproveitamento da palha da cana-de-açúcar para cogeração de energia numa usina sucroalcooleira. Dissertação (Mestrado) - Faculdade de Engenharia de Ilha Solteira, Universidade Estadual Paulista, Ilha Solteira.

Salgado Junior, A. P., C. A. G. Bonacim, and A. C. Pacagnella Junior. 2009. Aplicação da análise envoltória de dados (DEA) para avaliação de eficiência de usinas de açúcar e álcool da região nordeste do estado de São Paulo. *Organizações Rurais e Agroindustriais (UFLA)* 11: 494 - 513.

Senra, L. F. A. de Castro, L. C. Nanci, J. C. C. B. S. de Mello, and L. Ângulo Meza. 2007. Estudo sobre métodos de seleção de variáveis em DEA. *Pesquisa Operacional* 27 (2): 191-207.

Sermatec. http://www.sermatec.com.br [accessed August 18, 2012].

Smeets, E., M. Junginger, A. Faaij, A. Walter, and W. T. Dolzan. 2008. The sustainability of Brazilian ethanol: an assessment of the possibilities of certified production. *Biomass and bioenergy* 32: 781-813.

Sobiologia. http://www.sobiologia.com.br/conteudos/Solo/Solo8.php/ [accessed August 19, 2012].

Staut, L. A. Condições dos solos para o cultivo da cana-de-açúcar. http://www.cpao.embrapa.br/portal/artigos/artigos/artigo18.html/ [accesses August 18, 2012].

The World Bank. http://www.data.worldbank.org/data-catalog/GDP-ranking-table/ [accessed August 14, 2011].

Torquato, S. A. 2006. Cana-de-açúcar para indústria: o quanto vai precisar crescer. *Análise e indicadores do agronegócio* 1 (10).

Torquato, S. A., R. Martins, and S. F. Ramos. 2009. Cana-de-açúcar no Estado de São Paulo: eficiência econômica das regionais novas e tradicionais de produção. *Informações Econômicas* 39 (5).

União da Indústria de Cana-de-açúcar (UNICA). http://www.unica.com.br/ [accessed November 30, 2011].

Yin, R. K. 2010. *Estudo de caso: planejamento e métodos*. 4. ed. Porto Alegre: Bookman.

Appendix

Chart 6. Map of the agricultural potential in Brazil's main states

State	Average Relative Operational Efficiency	Characteristics	Recommendations
São Paulo	85.20%	Predominance of favorable edaphoclimatic conditions for growing sugarcane, greater operational efficiency of plants by state, high cost of land.	Good conditions favor the plants' operational efficiency; it is necessary to consider possible high production costs with eventual gains in efficiency.
Alagoas	82.18%	Second highest average operational efficiency by state, existence of regions with favorable types of soil for growing sugarcane, such as reddish-yellow latosol. Lowest standard deviation for the efficiency score by state.	Region is good for the production of sugar and ethanol; investment in technologies [needed] where a [high] frequency of favorable edaphoclimatic conditions [prevail].
Minas Gerais	79.74%	Climatic conditions favorable for growing sugarcane; variability of soil types; existence of favorable soils; high variability of average operational efficiency.	Necessary to invest in specific regions with favorable edaphoclimatic factors; important to increase investment in equipment and technologies to increase efficiency.
Pernambuco	79.56%	High variability in soil and climate; existence of regions with favorable soils for growing sugarcane.	Presence of favorable edaphoclimatic conditions. High agricultural potential; more investment needed in equipment and technology.
Mato Grosso do Sul	79.43%	High variability in soil types and climate. Existence of reddish-yellow and red latosols.	Search for specific edaphoclimatic conditions, found at lower frequency in the state, plus investment in equipment.
Paraná	79.29%	Existence of soils favorable for growing sugarcane; frequency of red latosol and predominantly wet, tropical climate.	Certain favorable regions whose edaphoclimatic factors favor investment; investment in equipment and technology needed to increase efficiency.
Mato Grosso	77.37%	Highest standard deviation for the average operational efficiency score; high variability in soil types and climate.	Search for specific edaphoclimatic conditions, found at lower frequency in the state, plus investment in equipment.
Goiás	73.84%	Lowest average operational efficiency among those states studied; favorable climate and high variability in soil types; existence of red latosol.	Investment needed in equipment and technologies. Represents great agricultural potential by virtue of the frequency of favorable edaphoclimatic conditions.

