Costs of Agronomic Practices: Profitability at Different Scales of Sugarcane Production in Brazil

Marco Tulio Ospina Patino[1], Fernando Rodrigues de Amorim[2], Alequexandre Galvez de Andrade[2], Mohammad Jahangir Alam[3] & Federico Del Giorgio Solfa[4]

[1] School of Agricultural Engineering (FEAGRI), University of Campinas (UNICAMP), State of São Paulo, Brazil

[2] Federal Institute of São Paulo, State of São Paulo, IFSP, Brazil

[3] Professor, Department of Agribusiness and Marketing, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh

[4] University of La Plata (UNLP). Researcher & INART Member, CIC-PBA, Brazil

Correspondence: Marco Tulio Ospina Patino, School of Agricultural Engineering (FEAGRI), University of Campinas (UNICAMP), State of São Paulo, Brazil.

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Abstract

The diversity in agronomic practices being used by sugarcane producers in Brazil determines differences in economic performance and cost structure. The purpose of this study is to evaluate the cost of six systems of agronomic practices using fixed or variable rates for soil amendment, fertilizer, and defensive applications and assess the profitability of these systems at three scales of sugarcane production. We then describe the data sample related to the 2019–2020 harvest season and collected from fifty-five sugarcane producers in the central-south region of Brazil. Thereafter, using a quantitative approach, a cost analysis was performed, and the cumulative frequency of the net revenue for the three scales of production (small, medium, and large), was calculated using a Monte Carlo simulation. The cost analysis indicated that fertilizer had the highest cost considering the agronomic practices adopted at the three scales of production analyzed. The cumulative frequency analysis results from the Monte Carlo simulation showed the highest net revenue per hectare for medium sugarcane producers. In addition, the presence of economies of scale was not confirmed because the lowest cost was found in small-scale sugarcane producers and the highest net revenue was obtained by medium-scale sugarcane producers.

Keywords: sugarcane, mechanization, variable rate, cost production, monte carlo simulation

1. Introduction

Globally, Brazil is the largest producer of sugarcane, representing 39% of production and 45% of the world's second National Supply Company (Conab, 2020). Therefore, the sugar and ethanol sectors have invested substantially in the development of new technologies and management systems to meet the global market demand outside (of sugar) and internationally (biofuel and bioenergy) (Zambianco & Rebellato, 2019; Carvalho et al., 2019; Manoel et al., 2016).

Although the literature commonly refers to three main products (sugar, alcohol, and energy), it is important to note that the sugarcane agroindustry produces a growing range of other end-use by-products and intermediate raw materials (Manoel et al., 2016). Many of these by-products are destined for wholesale and retail industries, such as orange juice and animal feed industries, as well as plant residues, such as vinasse and biofertilizers (Silva; Marques, 2017).

During the 2020-2021 crop season, the reduction in sugarcane quality and productivity resulted in a monetary decrease for producers Sugarcane Industry Union (Unica, 2021); hence, sugarcane producers had difficulties in obtaining satisfactory income (Cardoso et al., 2019). In this case, drought and frost will occur in 2021 in the center-south region of Brazil. Differences in the performance of agronomic practices were also associated with the size of the farm Amorim et al. (2018), Amorim et al. (2019), Pavlu; Molin (2016), Carvalho et al. (2011), and Baio et al. (2018), also affecting the profitability of sugarcane production. Bernardo et al. (2019) used bibliographical and documentary materials to analyze the evolution of sugarcane production in Brazil.

However, according to Unica (2021), if the weather is unfavorable, the drop in production has been driving the price of total recovered sugar (TRS). The comparison of the closing value of the TRS between 2010/11 (R$ 0.4022), 2020/21, and 2020 (R$ 0.6387) shows an increase of 58%.

Empirical studies have evaluated the productivity and total recoverable sugar (TRS) per ton in two forms of nitrogen application (Castro et al., 2014). Economic feasibility was analyzed by Amorim et al. (2019), Demattê et al. (2014), Pavlu; Molin (2016), Silva; Marques (2017), and, Osaki (2019), Pavlu & Molin (2016), and analyzed risks, and the results of these studies indicated greater economic feasibility using the variable rate system. Other authors Amorim et al. (2019); have studied the economic feasibility of different scales of production in Brazil and Niko et al. (2013) found that the expansion of sugarcane production in Brazil was accompanied by an increase in costs and yield decreases (Pavlu & Molin, 2016; Baio et al., 2018).

Therefore, the main contribution of this study is the analysis of detailed and stratified primary data on the cost of labor, mechanization, and inputs for each practice within the agronomic activities of sugarcane crop production. This study aimed to analyze the costs of six agronomic practices associated with windrowing in straw, un-windrowing in straw, and soil amendments, fertilizer, insecticides, and herbicide application using two methods: fixed rate and variable rate systems. These agronomic practices are widely used by sugarcane producers, and their costs have been used to assess the profitability of three scales of sugarcane production in Brazil.

2. Method

Using a probabilistic approach, a sample comprising data from 55 sugarcane producers was established for a finite sample with a confidence level (CL) of 90% and an estimated error of 3%, considering the 18.078 producers of sugarcane from the central-south region organization of cane producer associations in Brazil (Oliveira & Nachiluk, 2011). This CL yielded a sample of 52 producers. Here, independent producers who supplied 1.000 metric tons of sugarcane, which was harvested from approximately 10 hectares, were selected from the to 2018-2019 harvest.

The sugarcane producers filled out a questionnaire either in person or via email during November 2019 and March 2020. The questionnaire comprised of 50 questions based on the related systems used in sugarcane agronomic practices and their associated costs.

The questionnaire was validated by 11 respondents with ample knowledge about the sugarcane sector, including four academics, four producers, and three professionals from local sugar industries. The validation was done by using a five-point Likert scale, where 1 (one) corresponds to strongly disagree, 2 (two) to disagree, 3 (three) to neutral, 4 (four) to agree, and 5 (five) to strongly agree.

All participants consented to the Free and Informed Consent Term-Elaborated, Ministry of Health, under the guidelines of the Research Ethics Committee. Moreover, they provided information on the costs of each stage, such as labor, mechanization, inputs, number of cane cuts, field, type of agronomic practices adopted, productivity per hectare, total recoverable sugar (TRS), and type of application for soil amendments, fertilizers, and pesticides.

Producers were stratified using annual gross agricultural income criteria: the gross annual income for small-scale producers (n = 5) was up to US$71,570; medium-scale producers (n = 18) between US$71,571 and US$ 318,091, and large-scale producers (n = 32) over US$318,092 of gross income (Brasil, 2018).

The average values for each group were used as indicators in the statistical analysis of costs and gross income. Descriptive statistical analysis was performed using BioEstat 5.3 program (1995). The normality hypothesis of the data was tested using the Shapiro-Wilk test at a significance level of 5% once the data validation was performed in small sample (4–30) units (SHAPIRO; WILK, 1965).

The costs per hectare were calculated using equation 1:

$$TC = \sum (AA+HERB+WIND+UNWIND+AIS+AFSTO+AFWA) \quad (1)$$

$$\mathbf{TC = \sum(AA + HERB + WIND + UNWIND + AIS + AFSTO + AFWA)}$$

Where:

TC= Total cost; AA = Application of soil amendments; HERB = Application of the herbicide; WIND = Windrowing straw of sugarcane; UNWIND = un-windrowing straw of sugarcane; AIS = Application of insecticide; AFSTO = Application of fertilizers with the triple operation system; AFWA= Application of fertilizers with the air system.

A correlation measure was also used and applied when no variable or group of variables were treated as dependent or independent. Spearman's correlation uses a categorized estimate with a correlation value that varies between 1 and -1, where negative values represent an inverse correlation. When the value of one variable increased, the other decreases (0.50–0.69, moderate positive (negative) correlation; 0.70–0.89, high positive (negative) correlation; and 0.90–1.00, very high positive (negative) correlation) (Mukaka, 2012). Correlations of < 0.50 were considered weak; hence, they were discarded.

The value of sugarcane per ton was estimated using equation 2:

$$PPMTS = VTRS * QTRS * PROD \tag{2}$$

Where:

PPMTS =price per metric ton of sugarcane; VTRS = value (in kilograms) of total recoverable sugar; QTRS = quantity (in kilograms) of total recoverable sugar per hectare; *PROD* = Total production (Tons of sugarcane per hectare).

The average price per metric ton of sugarcane was determined based on TRS-accumulated data from February 2020 (R$ 0.6487) (Consecana, 2020). The value of TRS multiplied by the productivity and quality of raw materials converged to the value of sugarcane/ton. The values in the BRL of sugarcane/ton were converted into US dollars using the average exchange rate for Brazilian currency (US$ 1 = BRL 5.0).

To minimize the subjectivity of mean values, a Monte Carlo (SMC) simulation was performed using the Oracle Crystal Ball software (version 11.1) to provide an analysis of the projections using a stochastic approach.

The minimum and maximum numbers of simulations are not precise in the SMC literature. However, the maximum number of available programs was chosen. Therefore, SMC 50000 simulations were performed based on the analysis of the average revenues minus the average production costs of sugarcane suppliers. The same number of interactions were performed by (Silva et al., 2019).

The number of repetitions in this distribution provides other values obtained from these variables, yielding new results and determining the likelihood of success or failure of a particular activity. This type of distribution has been used by (SILVA et al.., 2019).

Rezende & Richarson (2017) and Amorim et al. (2019) conducted studies using this tool for sugarcane production. A unique feature of this simulation technique is its ability to assess risk in the presence of uncertainty without consolidated information. Osaki et al. (2019) used SMC to analyze different production systems, costs, and profitability. and Carvalho et al. (2014) found that SMCs are used to recover the probability distribution of the net present value (NPV) of two technological alternatives: a standard sugarcane mill and a flexible mill. SMCs have different models, but they share some aspects, such as the level of certainty, certain interval (coefficient of variation, standard deviation, average, maximum, minimum, and mean standard error), and highly accurate estimates.

The premises were defined through a normal distribution using the standard deviation of each assumption (mechanization, labor, and inputs). An increase and decrease of 5%, which refers to the difference between the average cost and the average gross revenue, were used to define the forecast of cumulative frequency.

According to Carvalho et al. (2014), the value of the variable of interest was simulated using the following equation 3:

$$\mathbf{a_m} = \frac{1}{r} \sum_{i=1}^{n} x_i. \tag{3}$$

Where:

a_m is the average SMC result for the variable of interest, interest a, $x$consists of the individual result of each simulated iteration, and n is the number of simulations (iterations). A sufficient number of iterations is necessary to obtain meaningful and reliable results.

3. Results and Discussion

The agronomic practice analyses are presented in (Table 1), which describes the six systems used by producers at fixed and variable rates.

Table 1. Description of the agronomic practices used by sugarcane producers

Agronomic practices operating systems	
Fixed Rate (FR)	**Variable Rate (VR)**
Fixed rate: Uniform application of fertilizers and agrochemicals across the entire area, with the average calculated via soil analysis.	Variable rate: Application of fertilizers and agrochemicals according to each point analyzed by grid or management zone.
AAFR. Application of soil amendments: using machinery (tractors, wheel loaders, implements, and trucks). Limestone and gypsum application with a fixed rate for control of PH and acidity on the ground.	**AAVR. Application of soil amendments using variable rate:** Using machinery (tractors, wheel loaders, implements, and trucks). Limestone and plaster application with according to each point analyzed by grid or management zone for control of PH and acidity on the ground.
HERBFR. Application of herbicide using fixed rate: using machinery (tractors, implements, and trucks). Herbicide application with a fixed rate for weed control in sugarcane.	**HERBVR. Application of herbicide using variable rate:** Using machinery (tractors, implements and trucks). Herbicide application with a variable rate for weed control in sugarcane. Application according to each point analyzed by grid or management zone for control.
AISFR. Application of insecticide using fixed rate: using machinery (tractors, implements, and trucks). Insecticide application with a fixed rate for drills, *Diatreasaccharalis, Sphenophoruslevis, co*ntrol in sugarcane.	**AISVR. Application of insecticide using variable rate:** using machinery (tractors, implements and trucks). Insecticide application with a variable rate for drills, *Diatreasaccharalis, Sphenophoruslevis, con*trol in sugarcane. Application according to each point analyzed by grid or management zone for control.
AFSTOFR. Application of fertilizers with triple operation system using fixed rate: Using machinery (tractors, implements).	**AFSTOVR. Application of the fertilizers with triple operation system using variable rate:** Using machinery (tractors, implements). Application according to each point analyzed by grid or management zone for control.
AFWAFR. Application of fertilizers with air system (without incorporate fertilizers) fixed rate: Using machinery (tractors, implements).	**AFWAVR. Application of fertilizers with air system (without incorporate fertilizers) variable rate:** Using machinery (tractors, implements). Application according to each point analyzed by grid or management zone for control.
WINDROWING. Windrowing straw of sugarcane: Using machinery (tractors, implements) for the total removal of sugarcane straw.	**UN-WINDROWING. Un-windrowing straw of sugarcane:** Using machinery (tractors, implements) for the total removal of straw from the sugarcane line and interline.

Source: De Amorim et al. (2021, p. 478).

In the variables whose p-values were ≥ 0.05, the hypothesis of normality of the data was accepted, meaning that the data are more homogeneous and have a symmetrical behavior in relation to the average, while for other p-values, the data are heterogeneous.

The hypothesis of normality, where the data are more homogeneous and have symmetrical behavior in relation to the average, was confirmed for the reformed area, HERBFR, AISFR, and total and average costs in the medium-scale group of producers. Data normality was also confirmed for the production area, reformed area, windrowing straw, AAFR, HERBFR, and AISFR for large-scale sugarcane producers. It was not possible to test data normality for the variables in the small-scale farmers group because only five sugarcane producers were in this group.

Among sugarcane producers, large-scale (9%), medium-scale (12%), and none of the small-scale producers used the windrowing system for sugarcane production. There was practically no significant difference between the average scores (mechanization and labor). However, the medium producers had the lowest total cost (18.3%), as shown in (Table 2). Both results of the coefficient of variation show significant variation and heterogeneity of the sampled data (>30). The fact that the standard deviation shows that medium-scale producers have a higher value in relation to this type of agronomic practice indicates that they have different agricultural machines to carry out this activity.

Table 2. Total costs per hectare, percentage of total cost, and descriptive analysis in US$ of the agricultural operating system windrowing straw in sugarcane suppliers

Windrowing straw of sugarcane	Suppliers		
	Small	**Medium**	**Large**
Mechanization (US$ ha^{-1})	0	10.3	15.1
Labor (US$ ha^{-1})	0	15.3	15.1
Coefficient of variation	0	76.7%	53.1%
Standard Deviation	0	19.7	16.1
Medium	0	25.6	30.3
% Total Cost Mechanization	0	1,8%	2,7%
% Total Cost Labor	0	2,7%	2,7%
% Total Cost	0	4,5%	5,4%
Total Cost (US$ ha^{-1})	0	25,6	30,3

Source: Compiled by the authors.

Castro et al. (2014) stated that the presence of trash from sugarcane plantations promoted changes in agricultural management. Owing to the mechanized harvesting of sugarcane, the spittlebug was considered as a secondary pest, has become a key pest in sugarcane fields in the region. Thus, in some cases, the use of straw in the initial stage of plant sprouting can be an alternative for the successful elimination of agronomic practices of leafhoppers. Straw plays an important role in soil conservation and bioenergy production (Okuno *et al.*, 2019; Aquino, *et al.*, 2018); and increases sugarcane yield Aquino, *et al.* (2018). Carvalho *et al.* (2019) stated that straw removal affects sugarcane yields in all soil types.

For un-windrowing in the straw system, 31% of large-scale, 24% of medium-scale, and 40% of small-scale producers use this production system. There was a significant difference in the average scores for labor. However, small-scale producers had the lowest total cost of labor (74.6%) and the lowest overall cost (38.5%).

The lower labor costs of small-scale producers showed that this group of producers had more operational efficiency than the other groups (Table 3). However, the coefficients of variation for medium-scale producers (>30%) and large-scale producers (20–30%) were found to be high.

Table 3. Total costs hectare, percentage cost total, and descriptive analysis in US$ of the agricultural operating system un-windrowing straw in sugarcane suppliers

Un-windrowing straw of sugarcane	Suppliers		
	Small	**Medium**	**Large**
Mechanization (US$ ha^{-1})	5.9	10.3	10.3
Labor (US$ ha^{-1})	5.9	5.9	5.9
Coefficient of variation	0%	31.9%	29.1%
Standard Deviation	0	5.2	4,7
Medium	11.7	16.2	16.2
% Total Cost Mechanization	1,2%	2,0%	2,1%
% Total Cost Labor	1,2%	1,1%	1,2%
% Total Cost	2,3%	3,1%	3,3%
Total cost (US$ ha^{-1})	11,7	16,2	16,2

Source: Compiled by the authors.

Regarding the application of amendments, 66% (FR) and 34% (VR) of large-scale producers, 67% (FR) and 33% (VR) of medium-scale producers, and 100% (FR) of small-scale producers used this system. Cost per hectare, percentage of total cost, and descriptive analysis of agronomic practices in relation to the un-windrowing production system. Therefore, there is a greater predominance of the FR system at the three production scales.

Demattê et al. (2014) showed that the application costs of (VR) in small-scale areas are higher than those in large-scale areas. From the results of this research shown in Table (5), the middle-scale producers (VR) had a total cost of 25.7% lower than that (FR). Only the system (VR) was evaluated with the value of the average coefficient of variation (10–20%) and other values (20–30%), as shown in (Table 4).

Table 4. Average total costs per hectare (US$) and percentage of total cost, and descriptive analysis for the application of soil correctives (AC) by sugarcane suppliers

	Mechanization		**Labor**		**Inputs**		**Total Cost**				
Types of AC	**US$**	**%**	**US$**	**%**	**US$**	**%**	**%**	**MV**	**Total Cost**	**CV%**	**SD**
ACFR (1)	14.2	3,0	10.3	2,2	58.4	12,3	17,5	82.9	82.9	26.8	22.2
ACFR (2)	16.7	3,3	12.8	2,5	57.1	11,2	17,0	86.6	86.6	28.1	24.3
ACFR (3)	13.2	2,7	9.4	1,9	60.5	12,4	17,5	83.2	83.8	29.9	24.9
ACVR (1)	11.7	2,5	11.7	2,5	57.3	12,1	17,1	57.8	80.7	27	21.8
ACVR (2)	7.9	1,9	7.9	1,9	46.3	11,1	16,6	57.7	68.8	16.7	11.5

Note(s): (1) = large; (2) = medium; (3) = small; Mech = mechanization; MV = medium value; CV = coefficient of variation; SD = standard deviation; % = percentage of total cost. Application. The application of soil correctives does not appear in the table, because small suppliers do not apply correctives using variable rates.

Source: Compiled by the authors.

In Table 4, the results of less variability in the application of soil amendments using variable rates by medium-scale producers (AAVR2) are related to the lower use of lime and gypsum to correct soil acidity and pH. The use of a smaller quantity of the aforementioned products has a greater positive (homogeneous) correlation than the other groups and, therefore, has less variability; that is, they may be concentrated in a greater number of producers in the same region.

For herbicide application (Table 5), 84% of large-scale producers used a fixed rate (FR), 16% used a variable rate (VR), 78% used a fixed rate (FR) and a 22% variable rate (VR), and 100% of small-scale producers used the fixed-rate system. The lowest cost of herbicide application with variable rate by medium scale was found to be significantly different when compared to the cost of the same supplier application herbicide using fixed rate (medium scale) with a cost structure of 39,5% for mechanization, 18% for labor, and 71% for inputs (74%). Mechanized harvesting of sugarcane alters the composition of infesting weeds. Thus, medium-scale producers working at variable rates (medium-scale) chose to apply herbicides only to the locus of germinated weeds on straw sugarcane.

The results of the coefficient of variation of the system application of herbicide using fixed rate (large-scale) and application of herbicide using variable rate (small-scale; medium-scale) were considered high (20–30%), and the other values showed great variation (>30%) (Table 5). Most producers use herbicides in sugarcane to control weeds; however, according to producers, this is a costly operation. However, when weeds are not controlled, sugarcane productivity and longevity are low (Barcellos Júnior, et al. 2017).

Table 5. Average total costs hectare, percentage total cost, and descriptive analysis in US$ of the application of the herbicide in sugarcane suppliers

	Mechanization		Labor		Inputs		Total Cost				
Types of HERB	**US$**	**%**	**US$**	**%**	**US$**	**%**	**%**	**MV**	**Total Cost**	**CV %**	**SD**
HERBFR (1)	13.7	2,9	9.0	1,9	50.9	10,7	15,5	73.6	73.6	31.7	23.3
HERBFR (2)	15.9	3,2	10.5	2,1	49.6	9,8	15,1	76.1	76.1	36.6	27.6
HERBFR (3)	15.4	2,7	7.6	1,9	48.6	12,4	17,1	71.7	71.7	26.1	18.7
HERBVR (1)	19.0	4,1	17.0	3,6	38.7	8,3	16,0	76.6	74.6	28.9	21.5
HERBVR (2)	11.4	3,0	8.9	2,3	28.5	7,4	12,7	67.3	48.7	23.9	16.1

Note(s): (1) = large; (2) = medium; (3) = small; Mech = mechanization; MV = medium value; CV = coefficient of variation; SD = standard deviation; % = percentage of total cost. Application. The application of the herbicide does not appear in the table, because small suppliers do not apply correctives using variable rates.

Source: Compiled by the authors

For insecticide application, 87.5% of large-scale producers use fixed rates and 12.5% use (VR); 83.3% (FR) and 11.1% (VR) of medium-scale producers, 5.6% (no option), and 100% (FR) of small-scale producers used this system. The total cost of the insecticide application system did not differ significantly, and the average coefficient of variation was 10–20%. However, a difference between the input costs was observed between application of insecticide using variable rate (medium-scale), and application of insecticide using fixed-rate (large-scale) 45.1% (Table 6). This fact demonstrates the significant difference in costs with inputs (insecticides) between the FR and VR systems. One of the causes may be a higher incidence of pests in the producer region of the producer group application of insecticides using fixed-rate (large-scale), as well as, through the instruments of data collection of precision farming systems (VR), demonstrating that the pests of the producer region application of insecticides using variable rates (medium-scale) are in a small portion of the total area.

The sugarcane borer is one of the most common pests of sugarcane production in Brazil (Dinardo-Miranda, *et al.*, 2012) as *borer* causes significant losses in productivity and confirms input cost reduction when the variable rate (VR) system is used in insecticide application (Pavlu *and* Molin, 2016), corroborating our research results.

Table 6. Average Total costs hectare, cost/ton. /Cane, and descriptive analysis in US$ of the application of the insecticide in sugarcane suppliers

	Mechanization		Labor		Inputs		Total Cost				
Types of AIS	**US$**	**%**	**US$**	**%**	**US$**	**%**	**%**	**MV**	**Total Cost**	**CV%**	**SD**
AISFR (1)	18.7	3,9	10.5	2,2	104.6	22,1	28,2	133.8	134.0	12.7	17.1
AISFR (2)	20.8	4,1	13.8	2,8	100.3	20	26,9	134.9	135.0	14.3	19.3
AISFR (3)	20.8	4,3	17.2	3,5	98.3	20,2	28.0	136.3	136.3	17.8	24.3
AISVR(1)	24.8	4,6	18.5	3,4	97.6	18,3	26.3	140.8	140.8	10.4	14.6
AISVR(2)	24.7	6,1	17.3	4,3	47.2	23,3	34,4	139.	139.4	14.6	20.4

Note(s): (1) = large; (2) = medium; (3) = small; Mech = mechanization; MV = medium value; CV = coefficient of variation; SD = standard deviation; % = percentage of total cost. Application. The application of insecticide does not appear in the table because small suppliers do not apply correctives using variable rates.

Source: Compiled by the authors

The application of fertilizers at a fixed rate (FR) using the triple operation system was 31.3% for large-scale producers, 44.4% for medium-scale producers, and 40% for small-scale producers. Meanwhile, FR application was found to be 9.4% for large-scale producers, 5.6% for medium-scale producers, and 0% for small-scale producers. The cost of fixed-rate (FR) application of fertilizers with the air system was found to be 56.3% for large-scale producers, 33.3% for medium-scale producers, and 60% for small-scale producers. The cost with variable rate (VR) for fertilizer application was 3.1% for large-scale producers, 11.1% for medium-scale producers (5.6% for no option), and 0% for small-scale producers.

Moreover, 87.6% (large-scale producers), 77.7% (medium-scale producers), and 100% (small-scale producers) used FR application on the fertilizers; 12.5% (large-scale producers), 16.7% (medium-scale producers), and 0% (small-scale producers) used VR application on the fertilizers (average total cost hectare and descriptive analysis in US$ of the application of the fertilizers in sugarcane suppliers (Table 7).

Small-scale producers using fixed rates for fertilizer application had the lowest total cost among all producer groups, at US$186.9. This value was 8.5% lower than the result found by Amorim *et al.* (2019), which was US$171.5, corroborating the research results of Castro *et al*. (2014), and therefore indicates this operation system in the areas with mechanical harvesting of sugarcane. The system application of fertilizers with air system without incorporating fertilizers fixed rate (medium-scale) and (small-scale) presented the lowest coefficient of variation (<10%), while the others were (10 to 20%).

Table 7. Average Total costs hectare and descriptive analysis in US$ of the application of the fertilizers in sugarcane suppliers

	Mechanization		**Labor**		**Inputs**		**Total Cost**				
Types of FERT.	**US$**	**%**	**US$**	**%**	**US$**	**%**	**%**	**MV**	**Total Cost**	**CV%**	**SD**
AFTOFR (1)	30.7	7	17.8	1	159.9	34	44,1	208.4	208.5	14.8	30.8
AFTOFR (2)	34.7	7	19.8	1	144.0	30	41	198.5	198.5	11.3	22.5
AFTOFR (3)	34.7	7	24.7	5	139.1	28	39.3	198.5	198.5	17.8	35.1
AFTOVR (1)	28.1	6	14.8	3	154.0	33	42.8	196.9	196.9	n.a	n.a
AFTOVR (2)	34.7	7	14.8	3	183.8	38	48,7	233.3	233.3	n.a	n.a
AFWAFR (1)	27.5	6	15.9	3.4	147.9	31	40.4	191.3	191.3	14.1	27.0
AFWAFR (2)	26.4	5	14.8	3	149.0	30	38.5	190.2	190.2	7.9	15.0
AFWAFR (3)	24.7	5	14.8	3	147.3	30	37,6	186.9	186.9	3.1	5.7
AFWAVR (1)	24.7	5	34.7	7	163.9	32	36,9	188.7	188.7	n.a	n.a
AFWAVR (2)	24.7	5	24.7	5	168.9	34	37.8	190.2	190.2	n.a	n.a

Note(s): n.a., not applicable. (1) = large; (2) = medium; (3) = small; Mech = mechanization; MV = medium value; CV = coefficient of variation; SD = standard deviation; % = percentage of total cost. Application. The application of fertilizers does not appear in the table, because small suppliers do not apply correctives using variable rates.

Source: Compiled by the authors

The system application of fertilizers with an air system without incorporating fertilizers used FR and VR, if used to replenish the amount of nitrogen in cultural practices with urea or ammonium sulfate, will not allow the total amount of nitrogen available for the plant, because of the loss due to volatilization, as indicated by Amorim *et al.* (2018).

Most correlations were found in the productivity variable, followed by the average production costs, with an emphasis on the high positive correlation between the size of the area and the percentage of the reformed area. However, no correlation was found with the total recovered sugar (TRS) variable. This fact is confirmed by the results showing that the larger the size of the farm, the greater the percentage of the reformed area of sugarcane, and vice versa as the size of the farm decreases that area also decreases (Table 8).

Table 8. Total costs (US$) per hectare of the agronomic practices for different scales of sugarcane production

Agronomic Practice	**Scale of Production**								
	Small			**Medium**			**Large**		
	Cost (%)	**CV%**	**SD**	**Cost (%)**	**CV%**	**SD**	**Cost (%)**	**CV%**	**SD**
Mechanization	80.5 (16.5)	28.3	22.8	82.8 (17.3)	33.9	28.1	60.4 (12.8)	34.6	20.9
Labor	55.4 (11.4)	35.9	19.9	58.2 (12.2)	54.4	31.7	52.1 (11.0)	52.8	27.5
Inputs	351.5 (72.1)	13.7	49.3	337.0 (70.5)	17.5	59.1	360.4 (76.2)	6.8	23.9
Total Cost	487.4 (33)	-	-	478.1 (31)	-	-	473.0 (30)	-	-

Source: Compiled by the authors

The lowest results for mechanization and labor on the total costs of fertilizer application systems were found for large-scale producers, as shown in Table 9. This may be due to the type of technological packaging used. Dematt ê *et al*. (2014) stated that the technological packages of large-scale producers are more robust and support the theory that increasing the technological packages in the cultivation of sugarcane will decrease the cost of labor.

The input cost was over 70% of all groups, representing the highest cost of this activity, and careful attention from sugarcane producers in relation to production costs must be devoted to this variable. An alternative for cost reduction would be the mixing of chemicals with organic fertilizers, especially for producers who are close to sugar cane mills or those who have chicken or laying hen production in their regions.

In addition, Amorim *et al.* (2018) reported that sugarcane mills using sugarcane by-products (filter cake, ash, and vinasse) to replace 30 to 50% of fertilizer needs can reduce production costs and increase productivity per hectare, as evidenced by a moderate correlation (s = 0.61). The highest revenue, excluding the total cost of agronomic practices, was obtained by medium-scale sugarcane producers (Table 09). This group also achieved the highest percentage in the level of certainty for this result, minimizing the difference made by analyzing the average values from the intervals. Regarding the statistical analysis provided by the Monte Carlo simulation, the coefficient of variation showed slight dispersion (<10%) as well as a low standard deviation between the three groups.

When medium-scale sugarcane growers used windrowing and un-windrowing straw application of VR soil, there was a strong correlation in profitability per hectare. Large-scale producers had strong correlations with windrowing straw, application of the soil (VR), application of herbicide (VR), application of fertilizers with triple operation (FR), and application of fertilizers with an air system without incorporating fertilizers (FR).

Table 9. Values of cumulative frequency of average net revenue for sugarcane producers obtained from the Monte Carlo simulation

	Scale of Production		
Description	**Small**	**Medium**	**Large**
Level of certainty	90.3	97.4	45.6
Sure interval (US$)	924,5–1,022	963 – 1,177	983 – 1,089
Coefficient of variation %	4.4%	4.5%	4.4%
Standard deviation (US$)	42.3	48.1	42.8
Medium (US$)	979	1070	978
Maximum (US$)	1,163	1,268	1,147
Minimum (US$)	793	876	799
Mean Standard Error (US$)	0.19	0.21	0,19

Source: Compiled by the authors

The profitability of sugarcane producers is also affected by other factors, such as productivity per hectare and the value and quality of total reduced sugars (TRS). The variation in the profitability of producers was between US$1,118.6, US$2,081.50, and the cost was between US$276.00 and US$750 per hectare. The profitability did not discount the cost of cutting, transshipment, and transportation (CTT) operations, which vary between US$ 4.00 and 8.00 per ton depending on the distance from the farm to the sugar mills. This value can vary from US$240 to US$480 for 60 tons per hectare and from US$420 to US$840 for 105 tons per hectare of productivity.

Therefore, the results corroborate the statement of Martins *et al*. (2018) that organizations are facing a much more agile and competitive environment, demanding new techniques, soft competition, and new production models.

4. Conclusion

The study brought the cost comparison for small sugarcane producers, there are few literatures that deal with this topic for this segment. The analysis indicated that the lowest total cost for a small-scale sugarcane producer was US$276.40, with a gross income of US$6,500. The small-scale producers did not use windrowing, un-windrowing, soil (VR), insecticides (VR), herbicides (VR), or fertilizers with the triple operation system (FR). However, large-scale producers with a gross income of US $ 9,117 incurred the highest total cost (US $ 750.20). The producers did not use windrowing systems, un-windrowing systems, soil (VR), herbicides, insecticides (FR), or fertilizers with the triple operation system (VR). The lowest total cost of U$$473 by large-scale producers did not show significant cost differences from medium-scale producers and 3% for small-scale producers.

However, when applying soil amendments, 9% of sugarcane producers use windrowing, 31% use un-windrowing, 66% work with the fixed rate (FR), and 34% with the variable rate method (VR); when applying insecticides, 87.5% used FR and 12.5% used VR; when applying herbicides, 84% used the FR method and 16% used VR. When sugarcane producers applied fertilizers using the triple operation system, 31.3% used FR and 9.4% VR, whereas when they used the air system to apply fertilizers, 56.3% used FR and 3.1% VR. The cumulative frequency analysis results from the Monte Carlo simulation showed the highest net revenue per hectare for the group of medium sugarcane producers.

To confirm the presence of economies of scale, the expected output was that large-scale producers were attaining the least cost and the highest revenue per hectare, but this was not confirmed because the lowest cost per hectare (US$ 276) within the three scales of production was achieved by small-scale sugarcane producers and the highest net revenue per hectare (US$1,070), excluding the costs of agronomic practices, was obtained by medium-scale sugarcane producers. Future research should focus on analyzing the most representative costs within each stage of this activity in greater detail. It is recommended that this study be applied in several regions of Brazil and other countries to compare cost metrics considering regional production characteristics.

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