ISSN 2359-6562 (ONLINE) 2359-6562 (CD-ROM)

# OPTIMIZATION OF MECHANIZED FLEET AS A FUNCTION OF CULTIVATED AREA AT THE BEGINNING OF THE BIOENERGY BRAZILIAN PROGRAM (PRO-ALCOOL)

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**ABSTRACT**: In the 1960s, due to the US-Cuba crisis, Cuba, its largest supplier, lost the US sugar market. The Brazilian government has developed a strategy to occupy part of this market through the Sugar and Alcohol Institute (IAA), which took several actions to moderni the sugar and alcohol agroindustry. This strategy was the basis for the national biofuel alcohol production program (Proalcool) in 1975. Ethanol jumped from 0.6 to 3.4 billion liters from 1975 to 1979/80, significantly exceeding the production target. This feat stimulated the Planalsucar (IAA) research to conduct an extensive survey of the fleet of agricultural machinery and implements in 67 units. The general aim of the present paper was to provide a historical record of this unedited survey database. The specific goal was to analyze the variation in the number of tractors and implements per thousand ha as a function of the sugarcane planting area to study the optimization of equipment use. We determined the linear correlation coefficient and the regression equation for each device. All significant correlation coefficients showed a decrease in *the number of machines and implements per 1,000 ha* related to *cultivated area* as follows: the number of tire tractors, total power of tire tractors (kW), harrows, plowers, furrows, loaders, and cultivators (cultivating implements). In other words, the larger the property is, the smaller the need for tractors and implements per unit area. This work provided evidence of the performance of a process of the economy of scale in the sugarcane production system.

**Keywords:** mechanized fleet survey; economy-of-scale; sugarcane

# OTIMIZAÇÃO DA FROTA MECANIZADA EM FUNÇÃO DA ÁREA CULTIVADA NO INÍCIO DO PROGRAMA BRASILEIRO DE BIOENERGIA (PRO-ÁLCOOL)

**RESUMO:** Na década de 1960, devido à crise EUA-Cuba, este, seu maior fornecedor, perdeu o mercado norte-americano de açúcar. O governo brasileiro desenvolveu uma estratégia para ocupar parte desse mercado por meio do Instituto do Açúcar e do Álcool (IAA), que realizou diversas ações para levar à modernização da agroindústria sucroalcooleira. Essa estratégia foi a base do Programa Nacional de Produção de Álcool Biocombustível (Proálcool) em 1975. O etanol saltou de 0,6 para 3,4 bilhões de litros de 1975 a 1979/80, superando significativamente a meta de produção. O feito estimulou a pesquisa do Planalsucar (IAA) a realizar um amplo levantamento da frota de máquinas e implementos agrícolas em 67 unidades. O objetivo geral do presente artigo foi fornecer um registro histórico desse banco de dados de pesquisa não editado. O objetivo específico foi analisar a variação do número de tratores e implementos por mil ha em função da área de plantio de cana-de-açúcar para estudar a otimização do uso dos equipamentos. Determinamos o coeficiente de correlação linear e a equação de regressão para cada dispositivo. Todos os coeficientes de correlação significativos mostraram uma diminuição no número de máquinas e implementos por 1.000 ha em relação à área cultivada da seguinte forma: número de tratores de pneus, potência total dos tratores de pneus (kW), grades, arados, sulcadores, carregadeiras e cultivadores (implementos de cultivo). Ou seja, quanto maior a propriedade, menor a necessidade de tratores e implementos por unidade de área. Este trabalho forneceu evidências do desempenho de um processo de economia de escala no sistema de produção de cana-de-açúcar.

Recebido em 30/08/2022 e aprovado para publicação em 08/02/2023
DOI: http://dx.doi.org/10.17224/EnergAgric.2023v38n1p58-67

**Palavras-chave:** levantamento mecanizado de frota; economia de escala; cana de açúcar

## 1 INTRODUCTION

### 1.1 Status of sugarcane mechanization in Brazil

With the evolution of sugarcane production, there are current research efforts in favor of this culture. The sector presents several studies in line with the operation and performance of machines, such as studies on the level of mechanization by property size and region (ALBIERO *et al.*, 2019), the influence of the transition from manual harvest to the recently occurring mechanized harvest (GALVÃO *et al.*, 2018; STOLF; MATSUOKA, 2017; COELHO *et al.*, 2020), and studies on the distribution of billets, basal cutting and tillering (ORLANDO JUNIOR *et al.*, 2018; PAIXÃO et al., 2019; MATSUOKA; STOLF, 2012). An efficient effort for the employment of advanced precision agriculture techniques has also been verified (SANCHES *et al.*, 2019; MIRANDA; VERÍSSIMO; CEOLIN, 2017). In this last article, the authors report that among the cultures in Brazil, sugarcane stands out in the number of studies.

### 1.2 Evolution of the tractor market since the 1960s in Brazil

Several authors have studied the evolution of mechanization from the 1960s to the present (AMATO NETO, 1985; LIMA; SANTOS; AMATO NETO, 2017; SILVA; VIAN, 2017; SILVA; WINCK, 2019). According to Silva and Vian (2017), in the 2000s, among the 11 highest rates of tractor use per thousand ha, Brazil ranked 9: 1-Japan (500), 2-Italy (167), 3-Germany (100), 4-Poland (91), 5-France (71), 6-Spain (56), 7-Turkey (33), 8-USA (24), 9-Brazil (14), 10-India (9), and 11-China (6). Among the factors that affect the value are technological resources and the occurrence of small properties, as in Japan (500 tractors/1000 ha). The same authors estimated the world fleet of tractors at 25.5 million units; the largest fleets correspond to the USA (17%), India (9%), Japan (7%) and China and Italy (6%), while Brazil ranks 11th on the list with 3% of the world fleet.

Cosentino (2004) presents a variation curve of the mechanization index in Brazil from 1960 to 2000, and there was an increase in the number of tractors by $10^{-3}$ ha of cultivated land from 2.4 to 8 tractors.

### 1.3 The great leap in sugarcane agroindustry from the 1960s onward in Brazil and the context of this survey

The extraordinary development of sugarcane agribusiness from 1960 onward occurred for two main sequential reasons (STOLF; OLIVEIRA, 2020): the closing of the American sugar market to Cuba (Cuban crisis), which at the time was the largest producer in the world, and the Brazilian government's strategy through the IAA to occupy part of the US sugar market.

IAA created the "Export Division" and started to finance the industry, brought in a geneticist from Hawaii to develop a national plan for genetic improvement, and created the research agency "Planalsucar" to operate in all sugarcane regions in Brazil. In addition, it encouraged the participation of the private sector, for example, in the creation of a representative entity of the producers' class the Society of Sugar and Alcohol Technicians of Brazil (STAB) and the Sugarcane Research Center of Copersucar (BELIK, 1985; STOLF; OLIVEIRA, 2020; STOLF; MATSUOKA, 2023).

The fast evolution in a giant leap in the sugarcane agroindustry served as the basis for the next step: the creation of Proálcool to supply the Brazilian fleet of cars with biofuel in 1975. From this year to harvest 1979/80, ethanol production jumps from 0.6 to 3.4 billion liters (MICHELLON; SANTOS; RODRIGUES, 2008). Under great stimulus due to achievement, Planalsucar established a bold project to survey the fleet of agricultural machinery in the producing units described in the present study. Considering the absence of studies on the moto-mechanized fleet in the agricultural areas of sugarcane units in Brazil, this work aims to provide a historical record of the database of the survey, harvest 1979/1980. The specific goal is to correlate the index *"variation in the number of tractors and implements per thousand ha*" to the sugarcane area to analyze the dependency of these two variables.

## 2 MATERIALS AND METHODS

This work was part of a national project to collect data on agricultural mechanization in sugarcane, interrupted by the extinction of the IAA-Planalsucar, the state agency that regulated sugarcane production from 1930 to 1990 (STOLF; MATSUOKA, 2023). The survey occurred in all regions of Brazil on the 1979/1980 harvest. Data were centralized in the National Superintendence but lost with the interruption of the institution. The center-south headquarters held a technical report for this region, constituting the database of this work.

### 2.1 Data Volume

Sixty-seven production units with 12 mechanization variables were sampled each, for a total of 804 data points (67x12).

Considering that it is not usual for articles to adopt a large number of data and variables, it was necessary to develop an approach. Then, it became an additional aim, as it would contribute to developing a general data treatment methodology:

The agricultural property area was divided into 16 classes of 2000 ha each, up to 32000 ha, reducing the data volume to 192 (16x12). However, as there were no properties in 5 classes, the total data resulted in 120 (10x12), according to Table 1 and Figure 1 (presented in the results and discussion).

### 2.2 Mechanization index

The mechanization index adopted was "the number of each implement per unit of area (1000 ha)." For example, there are 50 tire tractors for 13000 ha in a sugarcane production unit. Therefore, the resulting index is 5,0 tractors per 1000 ha in the mentioned unit.

### 2.3 Variables regarding sugarcane area and the number of producing units

The survey took place in the harvest 1979/80 and covered 67 producing units in the Center-South region of Brazil, grouped at intervals of 2 thousand ha until class 30-32 thousand ha.

### 2.4 ClassVariables:

A: Class interval (every 2 thousand ha).

B: Class center (1, 3, 5... 31) in thousands of ha, representing the property area.

C: Number of producing units in each class.

### 2.5 Variables regarding tractors and implements per thousand hectares ($10^{-3}$ $ha^{-1}$):

D: Number of tire tractors.

E: Number of crawler tractors.

F: Total tire tractor power (kW) (1 HP= 0.7457 kW).

G: Total crawler tractor power (kW).

H: Number of agricultural harrows.

I.: Number of plowers.

J: Number of furrowers.

K: Number of harvesters.

L: Number of rakes.

M: Number of loaders.

N: Number of subsoilers.

O: Number of cultivators (cultivating implements)

Subsequently, linear regression was performed for each equipment variable (D to O) with the property size (B) to test the hypothesis of reducing variables with the increase in the property. The linear correlation coefficient (Pearson) was also applied and tested regarding the statistical significance by Student's t test for (*) 5%; (**) 1%; and (***) 0.1%.

### 2.6 Hypothesis:

The main objective is to verify whether the efficiency of its use increases or decreases with increasing planting area.

First step

H1: Test if the efficiency of each equipment use tends to increase with the planting area if the angular and regression coefficients b and R will be negative.

H2: Test if the efficiency of each equipment use tends to decrease with planting area if the angular and regression coefficients b and R will be positive.

Second step:

Test if the trend is statistically significant (Student's t test).

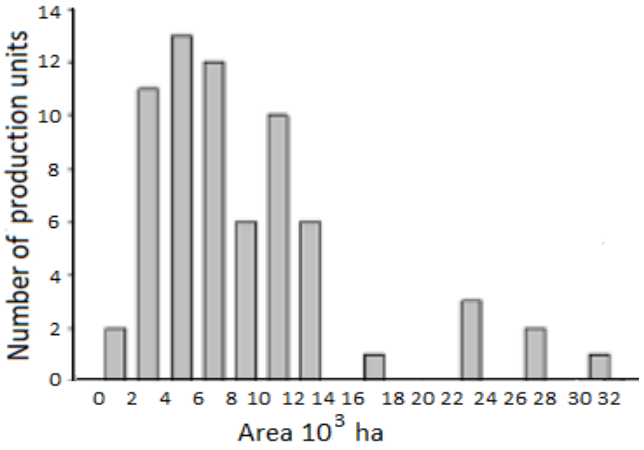
## 3 RESULTS AND DISCUSSION

The IAA-Planalsucar – Agricultural Mechanization Division, supporting PROALCOOL, implemented the research project in 1979/80 for all of Brazil: North, Northeast, East, and Center-South. After the field data survey, the government extinguished the IAA-Planalsucar, interrupting the project. The corresponding author saved a copy to avoid data loss. due to the discontinuity of IAA-Planalsucar.

### 3.1 Analysis of the economy of scale in the mechanized fleet

The distribution number of properties at 2000 ha intervals of cultivated area was the base for constructing the survey database (Table 1).

**Figure 1**. Distribution of the number of producing units with the size of the cultivated area in intervals of 2000 ha




**Source:** Author

**Table 1.** Database of the survey. Tractors and implements per thousand ha. Sixty-seven produce units are divided into classes from 0-2 to (0-32 thousand ha (class center from 1 to 31 thousand ha).

| **Area $10^3$ ha** | **Number of implements per thousand ha ($10^{-3}$ $ha^{-1}$)** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Class center | N.· properties (companies) | N. Tire tractors | N. crawler tractors | Total kW tire tractors | Total kW Crawler tractor | Harrows | Plowers | furrowers | harvesters | Rakes | Loaders | Subsoilers | Cultivators |
| B | C | D | E | F | G | H | I | J | K | L | M | N | O |
| 1 | 2 | 7.8 | 0.60 | 494 | 40 | 2.7 | 2.1 | 2.7 | 0 | 0.90 | 2.4 | 0.90 | 6.3 |
| 3 | 11 | 7.7 | 1.15 | 463 | 86 | 3.1 | 3.57 | 1.8 | 0.37 | 0.65 | 3.2 | 0.80 | 5.0 |
| 5 | 13 | 5.7 | 0.61 | 344 | 43 | 1.8 | 2.25 | 1.1 | 0.36 | 0.51 | 2.1 | 0.50 | 2.9 |
| 7 | 12 | 6.8 | 0.65 | 422 | 50 | 2.0 | 1.64 | 1.5 | 0.39 | 0.72 | 2.0 | 0.69 | 3.0 |
| 9 | 6 | 4.0 | 0.89 | 247 | 71 | 2.1 | 1.56 | 0.7 | 0.82 | 0.74 | 1.9 | 0.59 | 1.9 |
| 11 | 10 | 4.0 | 0.79 | 264 | 72 | 1.6 | 1.32 | 1.1 | 0.61 | 0.58 | 1.5 | 0.69 | 2.2 |
| 13 | 6 | 5.0 | 0.92 | 302 | 78 | 2.2 | 0.82 | 0.6 | 0.43 | 0.68 | 1.7 | 0.32 | 2.8 |
| 15 | 0 | | | | | | | | | | | | |
| 17 | 1 | 5.1 | 0.24 | 342 | 37 | 2.0 | 1.48 | 0.5 | 0.19 | 0 | 1.1 | 1.00 | 1.2 |
| 19 | 0 | | | | | | | | | | | | |
| 21 | 0 | | | | | | | | | | | | |
| 23 | 3 | 4.7 | 0.99 | 319 | 81 | 1.6 | 1.60 | 0.7 | 0.49 | 0.59 | 1.6 | 0.47 | 2.6 |
| 25 | 0 | | | | | | | | | | | | |
| 27 | 2 | 2.8 | 0.84 | 189 | 101 | 1.1 | 0.06 | 1.0 | 0.59 | 0.48 | 0.7 | 0.59 | 2.30 |
| 29 | 0 | | | | | | | | | | | | |
| 31 | 1 | 2.6 | 0.31 | 219 | 28 | 0.9 | 0.19 | 0.8 | 0.28 | 0.37 | 1.0 | 0.06 | 0.7 |
| Mean | | 5.1 | 0.73 | 328 | 62 | 1.9 | 1.51 | 1.1 | 0.41 | 0.57 | 1.7 | 0.60 | 2.8 |

OBS. : **(H)** Harrows: 25% light class and 75% medium and heavy classes. **(I)** Plowers: 57% hydraulic, 43% drag; **(K)** Harvester: chopped cane: 41% Santal; 11% Toft; 20% MF = 73%; whole cane: Artioli 27%
**Source:** Author

Taking an item for analysis, "the number of harrows by thousand ha" (Table 1, column H), the index decreased dramatically with the increase in the property area. This observation raises the hypothesis that the number of harrows per unit of the area would decrease with the size of the crop area. In other words, it would evidence a greater efficiency or lower idleness of this implement in the more size properties. Nevertheless, it is necessary to verify whether this decrease is statistically significant.

This hypothesis, tested by regression analysis and statistical significance of correlation coefficients, is shown in Table 2. Of all twelve, ten correlation coefficients presented an inverse relation trend (negative). Furthermore, seven of them presented statistically significant correlations, all inverse with property size, proving the hypothesis of index reduction with an increase in the area. In other words, the sugarcane production system has a scale economy process (Table 2). Therefore, the conclusion is that cultivated area size maximizes the use of equipment.

**Table 2.** Correlation and linear regression between x: cultivated area in $10^3$ ha, and Y: the number of implements by $10^3$ ha.

| **Variables** | **Linear equation** | **Correlation coefficient** | **Mean Y $10^{-3}$ ha$^{-1}$** |
|---|---|---|---|
| D: Tire tractors | Y= - 0.15x + 7.07 | R= - (0.833) ** | 5.1 tractors |
| E: Crawler tractors | Y= - 0.007x + 0.82 | R= - (0.263) ns | 0.73 tractor |
| F: Total power tire-tractor kW | Y= - 7.5x+ 428 | R= - (0.761) ** | 326 Kw |
| G: Total power crawler-tractor | Y= + 0.22x+ 59.4 | R= + 0.094 ns | 62 Kw |
| H: Harrows | Y= - 0.05x + 2.63 | R= - (0.841) *** | 1.9 harrow |
| I: Plowers | Y= - 0.08x + 2.54 | R= - (0.793) ** | 1.5 plowers |
| J: Furrows | Y= - 0.04x + 1.65 | R= - (0.607) * | 1.1 furrow |
| K: Harvesters | Y= + 0.004x + 0.36 | R= + 0.177 ns | 0.41harvest |
| L: Rakes | Y= – 0.013x + 0.74 | R= -0.543 ns | 0.57 rake |
| M: Loaders | Y= - 0.06x + 2.53 | R= - (0.839) *** | 1.7 loader |
| N: Subsoilers | Y= - 0.015x + 0.80 | R - (0.568) ns | 0.6 subsoil. |
| O: Cultivators | Y= - 0.11x + 4.3 | R= - (0.719) ** | 2.8 cultivat. |

(*): p< 0.05; (**): p<0,01; (***): p<000.1, and ns (no significance: p>0.05)
**Source:** Author

The results represent "a photograph" at that time, 1979/80 (Tables 1). Analyzing the behavior of some variables:

a) The number of plowers was still expressive, on average 1.51 per thousand ha, since today is not common, almost abandoned in the sector, for large areas.

b) 27% of the total harvesters were still of whole cane and were also abandoned.

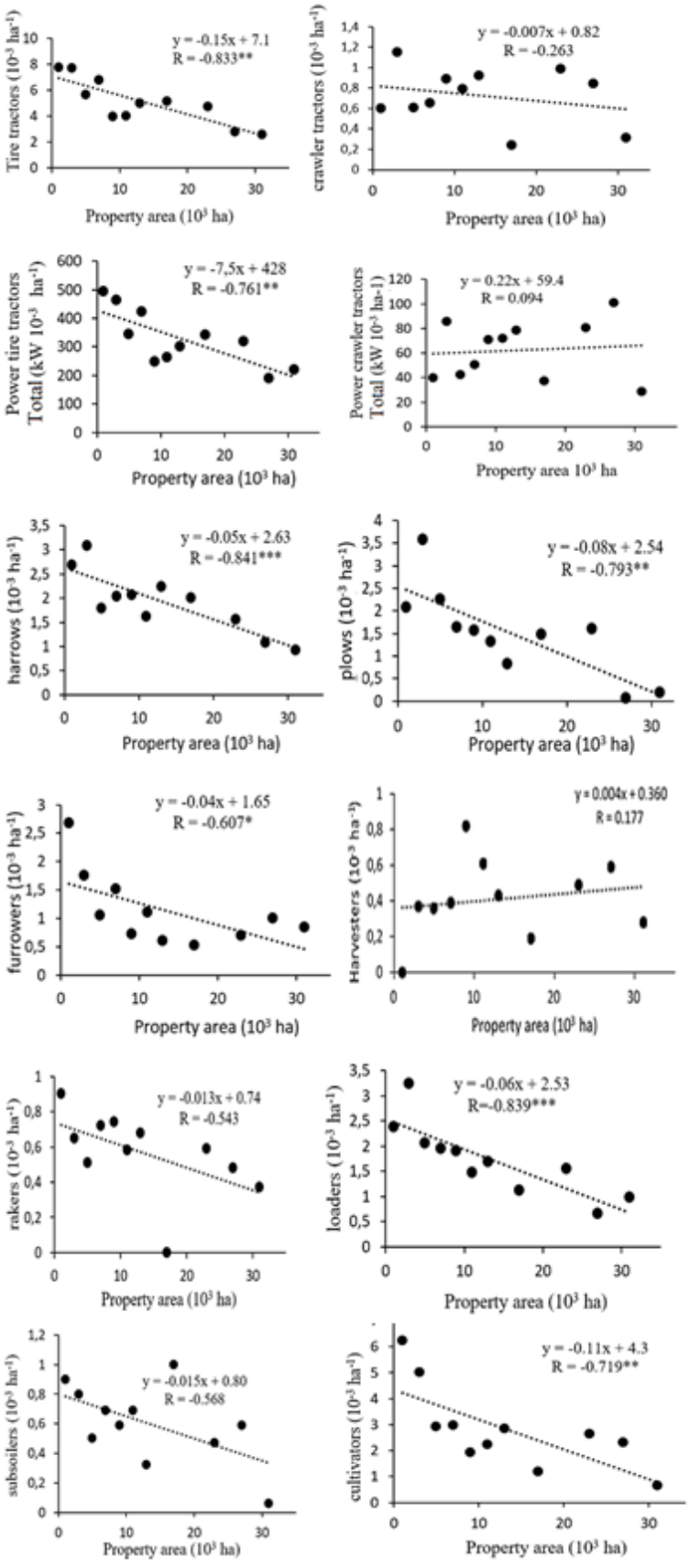
c) It is possible to verify a relatively low mean power for a single-tire tractor unit of 63.9 kW (326/5.1).

d) The total kW in the tire tractor was 5.3 higher than that in the crawler tractor.

Therefore, this survey can contribute to studies on the evolution of sugarcane moto-mechanization since, for this purpose, it is necessary to access data from the past, which are almost nonexistent in sugarcane.

Figure 2 represents the variation of implements number with the size of the cultivated area, where it is easy to analyze the increase or decrease through the trend line.

**Figure 2.** Number of each agricultural implement in relation to the size of the property.




**Source:** Author

It is interesting to observe that the scale of production of the units in the sugarcane sector has been rising continuously until the present, with the incorporation of the smaller units by the larger ones. Thus, there is evidence of a process of scale economy acting on the sugarcane production system, detected in the past, harvest 1979/80, by this study. In agreement with the results, there has been continuous growth in the agricultural area of the units to date, as well as a tendency toward forming conglomerates: the São Martinho mill unit (Pradópolis, SP) reached approximately 100 thousand ha. Raizen, the largest conglomerate in Brazil, has a set of units with centralized administration that manages approximately 1.000.000 ha (one million ha).

## 4 CONCLUSIONS

a) Of the 12 obtained correlation coefficients, seven of them presented statistically significant results, all negative, i.e., none positive: tire tractors, power for tire tractors, harrows, plows, furrower, loaders, and cultivators, proving the hypothesis of machinery index reduction with the increase in the cultivation area. In other words, the sugarcane production system has a process of the economic scale where size maximizes equipment use.
b) Considering that it is not common to adopt so many variables (12) and properties (67), 804 data, it was necessary to apply a method (item Data voliume) that would allow transforming the result into a database as a record for present and future use (Table 1). Thus, it was concluded that the methodology was adequate for data processing.

## 5 ACKNOWLEDGMENT

Project funded by The Institutional Support Foundation for Scientific and Technological Development of the Federal University of São Carlos (FAI – UFSCar)

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