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An environmental management method for sugar cane alcohol production in Brazil

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Abstract

This paper presents an environmental management method, focusing on environmental efficiency for agro-industry. The main idea is to perform a joint analysis of the ecological, economical and social aspects related to agro-industrial activities. The result of the analysis is a measurement of environmental efficiency, on a numerical scale. The lower values, encompassing 70% of the scale range, classify the low environmental efficiency activities. The values taking the upper 10% reveal the high efficiency ones. A case study focusing on the Brazilian alcohol production, including the agricultural and industrial phases, is presented. The study emphasizes the impact on the soil, water and air. Moreover, it also deals with the social and economic aspects related to the level of employment and productivity. According to the assumptions adopted, none of the three agro-industries analyzed achieved the highest environmental efficiency level established.

Keywords: Environment; Environmental management; Environmental efficiency; Alcohol; Ethanol; Sugar cane; Biomass; Bioenergy

1. Introduction

The production of alcohol in Brazil was initiated on a large scale in 1975 in the National program for Alcohol (1975–1985). At present, Brazil produces 2.6×10^8 tons of sugarcane, which is processed by 324 sugar mills to produce sugar and alcohol. The mid-south region, which corresponds to 17.60% of the country's area, produces 74% of the sugarcane and has the biggest concentration of these sugar mills, a total of 241 units. The state of Sao Paulo, which is in this region, has 133 sugar mills and is responsible for 76% of the production from the mid-south region.

In the initial aims of the National Alcohol Program, there was a lack of explicit concern with regard to planning or environmental impact. This research deals with the evaluation of environmental aspects in terms of the production of ethanol in Brazil. The objective is to propose an evaluation method, which integrates issues such as environmental problems and also considers social and economical aspects. The method has been applied to three alcohol mills, which are small, average and large. As a result, an indicator of the environmental quality of the work carried out in the factories, called "environmental performance" that

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points out which and how productive activities can be improved, was obtained. The relationship between factories and their environmental performance (low, average or high), describes the quality of the relationship with the environment. These factories should achieve a high performance category, to indicate their high productivity and environmental quality standards. None of the three mills studied reached the highest environmental performance level (A).

2. Environmental performance concept

Many scientific reviews Colby [1], Daly [2], Cavalcanti [3] and Pearce [4] discuss in a segmented and theoretical way, the preservation of the environment. The great majority point to the social-economical system as being the cause of depredation of environmental resources, but does not offer any methodology capable of establishing self-evaluation that demonstrates a specific productive activity and also its improvement with the environment. These discussions are global in character, but the solution is still local Costanza [5].

The environmental efficiency concept Borrero [6] used here deals with the evaluation of production activities based on economic and environmental criteria. The concept, in terms of the production of alcohol as a fuel, also considers the demand for natural resources a means of production and a receptor of the production residues.

Therefore, a high environmental performance of this activity is characterized by larger economical productivity (tons of sugarcane/hectare and/or liters of alcohol/ton of sugarcane) with lower demand for natural resources, as well as a higher employment level, which is an indicator of social welfare.

3. Evaluation methodology for the environmental performance of alcohol production

The production activities related to the use of the soil for sugarcane cultivation, the use of chemical inputs, the harvest, the use of liquor in the soil, the transportation of the sugarcane to the factories, the handling of the solid and liquid residues and the gaseous emissions, the production of alcohol and the production of energy from the burning of the bagasse, have been considered to represent the whole alcohol production process.

The social and economic aspects such as the creation of jobs and the increase in productivity were also taken into account. The methodology to obtain the indicators is explained in Table 1. The classification of the indicators was based on alcohol production from 3 case studies in Brazil.

Performances in physical, economical and social environments, for the use of soil, were considered. To determine the performance in the physical environment, 6 indicators were analyzed: (a) growth of the cultivated area, (b) use of the area for the cultivation of sugarcane, (c) agricultural productivity, (d) environmental damage (incorporation of new environmental areas for the cultivation of sugarcane, (e) concern about environmental recovery and (f) agricultural specialization (single crop use). Each one of these indicators was classified into three groups, as illustrated for the "growth of cultivated area" index. The indicator was classified as belonging to Group 1 (low performance) when the growth of the cultivated area exceeded 91%, to Group 2 (average performance) when the growth came between 90% and 50% and in Group 3 (high performance) when the growth was lower than 50%.

It can be noted, that in this case (and in some others), classification involves a certain degree of subjectivity, as the authors considered that the growth of the cultivated area, having been carried out mainly by the displacement of the other cultivations, would not be a desirable factor. If the growth of the cultivated areas had occurred using abandoned areas of land, the classification might have been different. The classification criteria for each one of the indicators can be obtained through a process of group discussion, involving the entire community. Other indicators such as the permanence (years) of chemical inputs in the soil are related to more commonly accepted standards, indicating less subjectivity in the classification. In the majority of the cases, the comparisons were made in relation to the average performance of the Copersucar [7] (The Sao Paulo State Sugar and Alcohol Producer Cooperative) 35 sugar and alcohol mills, which are responsible for the processing of almost a quarter of Brazilian sugarcane and considered as having the best performance

Table 1
Classification of the environmental performance

Quantifying the environmental performance		Group 1	Group 2	Group 3
Soil utilization				
(1) Performance of the use of soil for sugarcane cultivation on land	(a) Growth of the area	> 91%	90–49%	< 49%
	(b) Use of the area for sugarcane cultivation	> 81%	80%	< 79%
	(c) Agricultural productivity (t/ha)	Low < 66.9	Average 67–80.4	> 80.5
	(d) Environmental damage caused by the cultivation of sugarcane	Use of preserved areas	Use of forests and other spaces	Not measurable
	(e) Environmental recovery	Non-recovery of forests and other spaces	Recovery of forests and other spaces	Recovery of preserved areas
	(f) Agricultural specialization	Large (does not use crop rotation or alternation)	Average—constant or decreasing	Low—increasing
(2) Performance of the use of soil for sugarcane cultivation in an economic environment	(a) Dynamics of the activity	Decreasing	Constant	Increasing
	(b) Agricultural productivity (t/ha)	Low < 66.9	Average 67–80.4	> 80.5
	(c) Substitution of other food crops	Substitution of various cultivations	Substitution of one cultivation	Non-substitution
	(d) Agricultural specialization (crop alternation or rotation)	Large (no practice of crop rotation)	Average—constant or decreasing practice	Low—increasing
(3) Performance, at an employment level, of the use of soil for sugarcane cultivation in a social environment	(a) Activity dynamics	Decreasing	Constant	Increasing
	(b) Labor employment index for every 1000 harvested hectares	Decreasing	Constant	Increasing
Chemical inputs				
(4) Performance, on land, of the use of chemical inputs in the soil	(a) Toxic level of the chemical inputs	Large	Large	Low
	(b) Permanence of the inputs in the environment (years)	Large > 1	Average = 1	Low < 1
	(c) Use of chemical inputs	High—increasing index	Average—constant index	Low—decreasing index
	(d) Agricultural productivity (t/ha)	Low < 66.9	Average 67–80.4	> 80.5
(5) Performance of the use of chemical inputs in an economic environment.	(a) Use of chemical inputs	High—increasing index	Average—constant index	Low—decreasing index
	(b) Agricultural productivity (t/ha)	Low < 66.9	Average 67–80.4	> 80.5
Harvest				
(6) Performance, on land, of sugarcane harvesting	(a) Burnt area	Large > 61%	Average = 40–60%	Small—39%
	(b) Burning practice	Large—increasing or 100%	Average—constant	Low—decreasing
	(c) Mitigation of burning practice based on mechanization index	Low < 19%	Average = 20–30%	High > 31%

Table 1 (*continued*)

Quantifying the environmental performance		Group 1	Group 2	Group 3
	(d) Agricultural productivity (t/ha)	Low < 66.9	Average—67–80.4	> 80.5
(7) Performance of sugarcane harvesting in air resources.	(a) CO emission with the burning of sugarcane (t/year)	Large > 801	Average—700–800	Low < 699
	(b) Particular material emission with the burning of sugarcane (t/year)	Large > 801	Average—700–800	Low < 699
	(c) CH_4 emission with the burning of sugarcane (t/year)	Large > 801	Average—700–800	Low < 699
(8) Performance of the sugarcane harvesting in an economical environment.	(a) Loss of alcohol with the burning of sugarcane (%)	Large > 3	Average—1–2	Small < 1
	(b) Harvester fuel waste (l/t)	High > 1	Average—0.7–0.99	Low < 0.69
	(c) Harvester productivity (1000t/harvesters)	Low < 19	Average 20–50	High > 51
(9) Performance of the harvest in a social environment (at an employment level)	(a) Number of employees per 1000 ha harvested	Decreasing	Constant	Increasing
	(b) Potential for substituting men for machines	No mechanization	Incipient mechanization	Increasing index
Liquor disposal				
(10) Performance, on land, of the use of liquor	(a) Area irrigated with liquor %	Low < 19	Average 20–35	Large > 36
	(b) Irrigation tendency with liquor in %	Decreasing	Constant	Increasing
	(c) Liquor availability tendency in m^3	Decreasing	Constant	Increasing
	(d) Liquor application index per hectare (m^3/ha)	High > 150	Average = 150	Low < 150
	(e) Agricultural activity (t/ha)	Low < 66.9	Average 67–80.4	> 80.5
(11) Performance of the transportation of the liquor in air resources.	(a) Co emission due to liquor transportation	High > 2	Average = 0.5–1	Low < 0.49
	(b) NO_x emission due to liquor transportation (t/ha)	High > 2	Average = 0.5–1	Low < 0.49
	(c) SO_x emission due to liquor transportation (t/ha)	High > 2	Average = 0.5–1	Low < 0.49
	(d) Emission of Particulate Material due to transport of liquor (t/ha)	High > 2	Average = 0.5–1	Low < 0.49
(12) Performance of the application of the liquor in an economical environment.	(a) Economy of chemical fertilizers (t)	Low < 999	Mean = 1000–2000 Average = 1000–2000	High > 2001
	(b) Fuel expenditure (l/ha)	High > 100	Average = 95–100	Low < 94
	(c) Index for use of chemical inputs	Increasing	Constant	Decreasing
(13) Performance of the transportation of sugarcane in air resources.	(a) CO emissions (sugarcane t/t)	High > 2	Average = 0.5–1	Low < 0.49
	(b) NO_x emissions (sugarcane t/t)	High > 2	Average = 0.5–1	Low < 0.49
	(c) SO_x emissions (sugarcane t/t)	High > 2	Average = 0.5–1	Low < 0.49
	(d) Emissions of Particulate Material (sugarcane t/t)	High > 2	Average = 0.5–1	Low < 0.49

Table 1 (*continued*)

Quantifying the environmental performance		Group 1	Group 2	Group 3
(14) Performance of the transportation of sugarcane in an economical environment.	(a) Number of trucks per 1000 hectares cultivated	High > 8	Average = 4–7	Low < 3
	(b) Fuel expenditure (sugarcane l/t)	High > 1	Average = 0.7–0.99	Low < 0.69
Alcohol production				
(15) Performance, on land, of the industrial process:	(a) Use of solid residues in cultivation	Low < 69	Average = 70–90	High > 91
	(b) Area with filter cake application in %	Low < 24	Average = 25–35	High > 36
incorporation of solid residues in	(c) Area with ash and soot application in %	Low < 0.99	Average = 1–2	High > 3.1
the factory soil.	(d) % sludge applied to land	Low < 95	Average = 96–99%	High 100
	(e) Agricultural productivity (t/ha)	Low < 66.9	Average 67–80.4	> 80.5
(16) Performance of the industrial process in water resources.	(a) Use of water (m^3/liter of alcohol)	High > 9.1	Average = 8–9	Low < 7.9
	(b) Residual water outlet (m^3/l)	High > 0.3	Average = 0.11–0.29	Low < 0.10
	(c) Removal of liquid residues in water streams in (%)	High > 5%	Average 1–4.9	Low = 0
(17) Performance of the industrial process in air resources.	(a) CO_2 emissions from juice fermentation	High > 0.5	Average = 02–0.49	Low < 0.19
	(b) CO_2 emissions from the burning of bagasse	High > 0.5	Average = 02–0.49	Low < 0.19
	(c) NO_x emissions from the burning of bagasse	High > 0.5	Average = 02–0.49	Low < 0.19
	(d) Emissions of Particulate Material due to the burning of bagasse (t/t bagasse)	High > 0.5	Average = 02–0.49	Low < 0.19
(18) Performance of the industrial process in an economical environment.	(a) Sugarcane for the production of alcohol (%)	Low < 44.9	Average = 45%–55	High > 55.01
	(b) Industrial efficiency l alcohol/ton sugarcane (l/tsc)	Low < 78.9	Average = 79–85.4	High > 85.5
	(c) Effect of the use of solid residues in chemical dependency	Low = increasing	Average = constant	High = decreasing
	(d) Effect of the solid residues in agricultural productivity (t/ha)	Low < 66.9	Average 67–80.4	High > 80.5
Energy prod				
(19) Performance of energy	(a) Energy self-sufficiency %	Low < 94	Average = 95–97	High > 80.5
	(b) Electricity production (kWh/tsc)	Low < 10.9	Average = 11–14.9	High > 15
production in an economical environment.	(c) Electricity consumption (kWh/tsc)	High > 11.77	Average = 10.76–11.76	Low < 10.75
	(d) Sale of the electric energy surplus (kWh/tsc)	Low < 0.27	Average = 0.28–0.31	High > 0.32

Table 2
Scale of environmental performance and score for productive activity

Productive activities	Score		Activity production		
	Minimum	Maximum	(C) Low	(B) Average	(A) High
1 Use of soil	12	36	12 to 24	25 to 31	32 to 36
2 Use of inputs	6	18	6 to 11	12 to 15	16 to 18
3 Sugarcane harvest	12	36	12 to 24	25 to 31	32 to 36
4 Use of liquor	12	36	12 to 24	25 to 31	32 to 36
5 Sugarcane transportation	6	18	6 to 11	12 to 15	16 to 18
6 Alcohol production	16	48	16 to 33	34 to 43	44 to 48
7 Energy production	4	12	4 to 7	8 to 10	11 to 12
Total	68	204	68 to 142	143 to 183	184 to 204

of the country. This group of indicators is used as a basis for the comparison and evaluation of the information obtained in the factories. The authors believe that they form a model of environmental relationship necessary for mill work. In order to help the analysis, scores were given to the groups, as follows: Group 1 = 1 point, Group 2 = 2 points and Group 3 = 3 points. This way, establishing minimum and maximum punctuations, for each productive activity, becomes possible. A minimum score occurs when all the indicators of a productive activity are in Group 1 and a maximum score occurs when all the indicators are in Group 3, as illustrated in Table 2. All indicators were considered to be equally important. Activities which presented low performance (C) were those whose total scores were less than 70% of the maximum value, average performance (B) were those whose total scores were between 70% and 90%, and high performance (A) were those whose total scores were above 90%, as shown in Table 2 (Scale of Environmental Performance and Score for Productive Activity).

4. Method application

The method was applied to three mills that produce alcohol as fuel in the state of Sao Paulo. These were: The Sao Jose Mill, small capacity (7×10^5 tons of sugarcane/year), The Ester Mill, average capacity (1.3×10^6 tons of sugarcane/year) and The Santa Elisa Mill, high capacity (6×10^6 tons of sugarcane/year). The information needed to apply the method was obtained from answers to a specifically prepared questionnaire, by visits, interviews and analysis of the specialized literature. The fieldwork was carried out at the mills during 1999.

5. Results

The obtained data was compiled into 11 tables, one for each year, analogous to Table 1, however the columns referred to Groups 1, 2 and 3 substituted by the columns which refer to the mills, with the classification obtained for each indicator from each mill. The evolution of the global performance for each mill, obtained from the sum of the points given to the indicators during the 11 years, can be seen in Fig. 1 from 1987 to 1997. The average global production of the mills for the 11 years analyzed is summarized in Table 3 from 1987 to 1997.

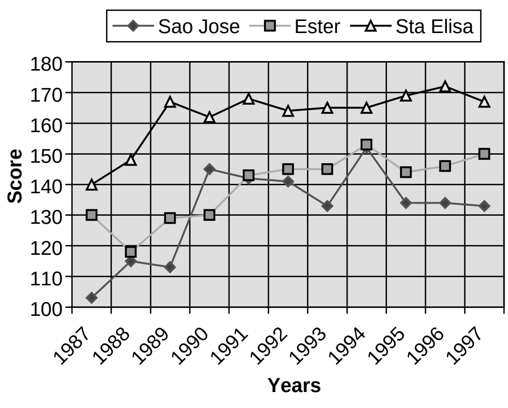

Fig. 1. Evolution of production in the mills. From 1987 to 1997.

Table 3
Quantification of environmental performance—average for 1987 to 1997

Quantification of environmental performance		Sao Jose	Ester	Santa Elisa
Soil utilization				
(1) Performance of the use of soil for sugarcane cultivation on land	(a) Growth in area	2	3	3
	(b) Use of the area for sugarcane	2	2	3
	(c) Agricultural productivity (t/ha)	3	2	3
	(d) Environmental damage to sugarcane cultivation	3	3	3
	(e) Environmental recovery	1	1	2
	(f) Agricultural specialization	1	2	2
(2) Performance of the use of soil for sugarcane cultivation in an economic environment.	(a) Dynamics of the activity	2	2	2
	(b) Agricultural productivity (t/ha)	3	2	3
	(c) Substitution of other food crops	2	2	2
	(d) Agricultural specialization (crop rotation or alternation)	1	2	2
(3) Performance of the use of soil for sugarcane cultivation in a social environment at an employment level.	(a) Dynamics of the activity	2	2	2
	(b) Labor employment index per 1000 hectares harvested	1	2	2
Total	Use of the soil	(C) 23	(B) 25	(B) 29
Chemical				
(4) Performance of the use of chemical inputs in the soil, on land	(a) Toxic level of chemical inputs	3	3	3
	(b) Permanence of chemical input in the environment (years)	3	3	3
	(c) Use of chemical inputs	1	1	2
	(d) Agricultural productivity (t/ha)	3	2	3
(5) Performance of the use of chemical inputs in an economic environment.	(a) Use of chemical inputs	1	1	2
	(b) Agricultural productivity (t/ha)	3	2	3
Total	Chemical inputs	(B) 14	(C) 12	(A) 16
Harvest				
(6) Performance of the sugarcane harvesting on land	(a) Burnt area	1	1	1
	(b) Burning practice	1	1	2
	(c) Mitigation of burning practice based on mechanization index	1	1	3
	(d) Agricultural productivity (t/ha)	3	2	3
(7) Performance of sugarcane harvesting in air resources.	(a) CO emission by the burning of the sugarcane (t/year)	1	1	1
	(b) Emission of Particulate Material in the burning of sugarcane (t/year)	1	1	1
	(c) CH_4 emission in the burning of sugarcane (t/year)	1	1	1
(8) Performance the sugarcane harvesting in an economical environment.	(a) Alcohol loss through the burning of sugarcane (%)	1	1	2
	(b) Harvester fuel expenditure (l/t)	1	1	3
	(c) Harvester productivity (1000t/harvester)	1	1	2

Table 3 (*continued*)

Quantification of environmental performance		Sao Jose	Ester	Santa Elisa
(9) Performance of the harvest in a social environment (at an employment level)	(a) Number of employees per 1000 ha harvested	1	2	2
	(b) Potential for substituting men for machines	1	2	2
Total	Harvest	(C) 14	(C) 15	(C) 23
(10) Performance of the use of liquor on land	(a) Area irrigated with liquor in %	2	2	2
	(b) Tendency of irrigation with liquor in %	2	2	2
	(c) Liquor availability tendency in m^3	3	2	3
	(d) Index of liquor application per hectare (m^3/ha)	1	2	1
	(e) Agricultural productivity (t/ha)	3	2	3
(11) Performance of the transport of liquor in air resources.	(a) CO emission through the transport of liquor (t/ha)	1	1	3
	(b) NO_x emission through the transport of liquor (t/ha)	1	2	3
	(c) SO_x emission through the transport of liquor (t/ha)	3	2	3
	(d) Particulate Material emission through the transport of liquor (t/ha)	3	2	3
(12) Performance of the application of liquor in an economical environment.	(a) Chemical fertilizer economy (t)	3	3	3
	(b) Fuel expenditure (l/ha)	1	2	0
	(c) Index of chemical input use	1	1	2
Total	Use of liquor	(C) 24	(C) 23	(B) 28
Transport				
(13) Performance of the transportation of sugarcane in air resources.	(a) CO emission (t/t of sugarcane)	3	3	3
	(b) NO_x emission (t/t of sugarcane)	3	3	3
	(c) SO_x emission (t/t of sugarcane)	3	3	3
	(d) Particulate Material emission (t/t of sugarcane)	3	3	3
(14) Performance of the transportation of sugarcane in an economical environment.	(a) Number of trucks for every 1000 hectares harvested	2	1	3
	(b) Fuel expenditure (l/t of sugarcane)	2	3	3
Total	Sugar cane transport	(A) 16	(A) 16	(A) 18
Alcohol				
(15) Performance of the industrial processing, on land: incorporation of the solid residues in the mill soil.	(a) Use of the solid residues in the field (%)	3	3	3
	(b) Filter cake in (%) applied in the area	3	2	3
	(c) Ashes and soot in (%) applied in the area	3	2	2
	(d) Iodine in (%) applied on the field	3	3	3
Production	(e) Agricultural productivity (t/ha)	3	2	3
(16) Performance of the industrial processing in water resources.	(a) Water use (m^3/alcohol liter)	3	2	2
	(b) Residual water outlet (m^3/l)	1	3	3
	(c) Disposal of liquid residues in the water streams in (%)	3	2	2

Table 3 (*continued*)

Quantification of environmental performance		Sao Jose	Ester	Santa Elisa
(17) Performance of the industrial processing in an air resource.	(a) CO_2 emissions form the juice fermentation (t/tc)	3	3	3
	(b) CO_2 emissions by the burning of bagasse (t/t bagasse)	3	3	1
	(c) NO_x emissions by the burning of bagasse (t/t bagasse)	3	3	3
	(d) Particulate Material emissions by the burning of bagasse (t/t bagasse)	3	3	3
(18) Performance of the industrial processing in an economical environment.	(a) Sugarcane for the production of alcohol in (%)	2	2	2
	(b) Industrial efficiency (liters alcohol/ton sugarcane)	1	2	3
	(c) Effect of the use of solid residues in chemical dependency.	1	1	2
	(d) Effect of the solid residues in agricultural productivity	3	2	3
Total	Alcohol production	(B) 41	(B) 38	(B) 41
Energy				
(19) Performance of energy production in an economical environment.	(a) Energy self-sufficiency in (%)	2	3	3
	(b) Electric energy production (kWh/tsc)	1	2	3
	(c) Electric energy consumption (kWh/tsc)	1	2	1
	(d) Sale of electric energy surplus (kWh/tsc)	1	2	2
Total	Energy production	(C) 5	(B) 9	(B) 9
General total of each mill		(C) 137	(C) 138	(B) 164

6. Analysis of the results

The evolution of the production of the mills (Fig. 1) shows that all three started off at different levels, had a significant evolution in the first four years of the study period and then practically stabilized. It can also be seen that the Santa Elisa mill operates at a better and at more constant production level than the others and comes close to the high production level. The Sao Jose mill presents a lower and more irregular production level.

A more detailed analysis of the results taken from the 7 constant production activities in Table 2, are presented below.

7. Use of the soil

Although there had been an increase in agricultural production (tsc/ha), the increase in production was obtained mainly by the use of more land for cultivation of sugarcane, for all three cases studied. In the Sao Jose and Ester mills, the growth of cultivated area was greater (above 50% of the initial availability) than that of the Santa Elisa mill.

During the study period the mills did not carry out this growth based on the use of natural spaces (forests, river bank vegetation etc.) and it should be noted that the Santa Eliza mill has increasingly recovered its river bank vegetation with the use of a reforestation program.

It is usual in Brazilian sugarcane cultivation for 80% of the available land to be used for the sugarcane cultivation, and the other 20% to be used for the restoration of the sugarcane plantation. In the Sao Jose mill, there is no crop rotation, and in the Ester mills, the orange plantation as an alternative activity is a decreasing practice, while in the Santa Elisa there is an increasing alternative activity, represented by the cultivation of other crops such as soya, peanuts, corn and sweet sorghum. The agricultural productivity of the Sao Jose, Ester and Santa Elisa mills averaged around 81, 75 and 89 tones of sugarcane per hectare (tsc/ha), respectively. Only the Ester mill showed decreasing tendency in their agricultural efficiency inferior to the Copersucar [8] 80 tsc/ha rate. Therefore only Santa Elisa factory presented an average performance classification (B) for the use of the soil, while the other two had a low performance classification (C) (Table 3).

8. Use of chemical inputs

Among the fertilizers and pesticides used for sugarcane cultivation, the chemical products of high toxicity and/or high level of permanence in the environment were not declared by the factories. Recently, the great majority of the pesticides are liquid, which makes their absorption by the environment quick and their incidence local. The Sao Jose mill had an average (B) performance, the Ester mill had a low (C) performance and the Santa Elisa mill had a high (A) performance. The relationship between the productivity and the utilization of the chemical inputs will be analyzed in another publication.

9. Harvest

It’s a common practice in Brazil to burn the sugar cane field to facilitate the harvesting process. This practice is responsible for the low environmental performance classification achieved by the mills in this research. In the Sao Jose and Ester mills, the burning practice reaches 100% of the sugarcane field. The harvest in the Sao Jose mill is completely manual, while at the Ester factory there is an increasing mechanization process. In the Santa Elisa mill, the harvest of raw sugarcane (not burned) has been increasing, reaching up to 48% of the cultivated area in 1997. Therefore, all three mills, although in different ways, contribute significantly to the emission of gas pollutants and consequently to the greenhouse effect. It is important to note that the emission of pollutants by the machines is insignificant compared to the emissions from the burning of the sugarcane plantation.

The burning of the sugarcane also presents a negative economic impact, as there is a loss of sucrose through the process of exudation caused by the high temperatures reached during the burning. The losses, due to the burning of sugarcane, are 3%, 4% and 2% out of the total alcohol production in the Sao Jose, Ester and Santa Elisa mills, respectively.

On the other hand, the loss of sucrose also occurs during mechanical harvesting, because the sugarcane is cut up during the process, causing exudation at the extremities of the pieces. However, information on the value of these losses is not available.

The low performances (c) obtained by the factories are due to the burning of the sugarcane plantations. It is also worth noting that the collection of raw sugarcane (no burning practice) leaves behind a great quantity of organic matter (specially leaves), which must be incorporated into the soil. This requires special knowledge and adequate handling in order to avoid the infestation of insects that can be harmful to sugarcane plantation, as in the case of the small grasshopper (Aethalion reticulatum).

10. Use of the liquor

It has been observed that the growth of the area for sugarcane cultivation is greater than the growth of the area irrigated with liquor. The irrigated area at Sao Jose mill had a decreasing tendency in relation to the total area harvested, reaching a radius of only 5 km. In this way, the liquor application rates correspond to an average of 358 m^3/ha, far more than the 150 m^3/ha considered acceptable. The Ester mill presented an increase in the irrigated area in relation to the collected area and has a radius of 18 km. Under these conditions, it can apply lower rates, in the order of 129 m^3/ha. Even though in the Santa Elisa mill there is an increasing irrigated area, reaching a radius of 25 km (recently reduced to 17), the 300 m^3/ha applied index is also superior to the 150 m^3/ha recommended.

The average for the irrigated area in the three cases was somewhere between 20% and 35% of the total area, reaching almost 50% at Santa Elisa. All three mills reached average qualification for the area irrigated with liquor (Table 3). Despite the fact that the application of liquor in the soil reduces theoretically the use of fertilizers (Table 3, item 12[a]), there has been an increasing use of chemical fertilizers in the Sao Jose and Ester mills. Santa Elisa mill showed a decrease in the use of these products. The limited range of the area irrigated with liquor in relation to the non-irrigated area can be the cause of the irregularity between theoretical economy and the effective chemical product use.

The emission of atmospheric pollutants, due to the use of diesel fuel trucks for the distribution of the liquor, is small when compared to the benefits obtained by the application of the product, but the environmental efficiency of this activity differs from one sugar mill to another. It is important to remember that the main environmental concerns due to the use of the liquor on the soil are linked to the infiltration and contamination of underground waters and with the evaporation of the polluting elements. These topics have not been dealt with in this research.

As shown in Table 3, the Classification of environmental performance of the sugar mills for this activity was low (C) for the Sao Jose and Ester sugar mills, and average (B) for the Santa Elisa sugar mill.

11. Sugarcane transportation

Fuel consumption for the transport of sugarcane was less than 0.7 liters of diesel for each ton of sugar cane transported. The amount of trucks used depends on their transport capacity. Special trucks, for sugar cane transport, which have a great cargo capacity to carry three times the normal amount per trip, were used. The amount of pollutants emitted was less than 0.5 tons for each ton of sugar cane transported. The three mills had high (A) performance for this activity.

12. The production of alcohol

Taking as a reference the 84.5 liters per ton of milled sugarcane from Copersucar [8], it can be seen that the Sao Jose mill, with an average of 76 liters per ton of sugarcane is far from the technological situation of other industrial installations in the state of Sao Paulo. This is not the case with the Ester and Santa Elisa mills, where both reach an average of 86 liters of alcohol per ton of sugarcane.

Based on Table 3, all the mills reached an average (B) level of production in industrial activity. This result is very much related to industrial waste management.

The production of alcohol (sugar-alcoholic activity in general) is based on the production of large amounts of solid, liquid and gaseous residues. Therefore the handling of these residues is added to the evaluation of industrial activity.

13. Handling of solid residues

The solid residues are filter cake, ash from burning the bagasse, soot from the boilers, and sludge from the treatment systems. In all three sugar mills analyzed, all the solid residues were incorporated into the soil (15a, 15b, 15c, 15d indicators in Table 3), which could help improve the quality of the soil and consequently increase agricultural production.

The incorporation of the solid residues into the soil, together with the application of the liquor, has not reduced the amount of chemical fertilizers used in both the Sao Jose and Ester mills. Just one, the Santa Elisa sugar mill had a reduction in the use of chemical fertilizers. The evaluation of 18c and 18d indicators (Table 3) not only shows the low impact of this activity in the reduction in the amount of chemical products used but also the low agricultural yields in the case of the Ester mill.

14. Handling of liquid residues

The liquid residues during the industrial phase of the production of alcohol are: liquor, sugar cane washing water, water from the condensers and from the cleaning of the equipment, apart from other residual water. The liquor was treated separately due to it being practically solely from sugar cane juice milling. This extract is extremely polluting as it contains approximately 5% organic material and fertilizers such as potassium, phosphorus and nitrogen.

Water has various uses in the industrial process, and it is most used for the sugar cane washing before the milling. (There are already techniques to eliminate this practice, which however are little used). The amount of water used in an industrial process is large generating a high level of liquid residues. A good idea is to use this water in a closed re-circulation and filter system circuit. The demand for water observed at the mills was 3 m^3/la (liters of alcohol produced) in the Sao Jose mill, 9 m^3/la at the Ester mill and 8 m^3/la at the Santa Elisa mill. However, the elimination of the residual waters is between 0.5 and 1.0 m^3/la for the Sao Jose mill and 0.03 m^3/la for the Ester and Santa Elisa mills.

The great difference in elimination occurs because in the Sao Jose mill only a fraction of the residual water is recycled, while in the Ester and Santa Elisa mills this recirculation is around 95% to 96% of the volume of residual water.

In the Sao Jose and Santa Elisa mills all the residual water returns to the soil, however in the Ester mill approximately 30% goes into a cooling lake and afterwards to the water streams (water from the evaporators and cooling of the distilling systems).

15. Handling of gas emissions

The emission of CO_2 is not considered a polluting emission as it is absorbed in the growth cycle of sugarcane. The quantities of the other gas emissions per liter of alcohol produced are insignificant. The Particulate Material (PM), emitted during the burning of the bagasse, is basically made up of soot and ash. Soot, which is practically pure carbon, is a problem when the mills are located near the cities, which makes its control a must. In the three cases studied, the Particulate Material was removed by a gas washer and incorporated into the soil.

16. Production of energy

The energy obtained by the burning of sugar cane bagasse in the mill itself provided self-sufficiency, in terms of energy, for the three cases studied. Apart from being economically important, it was also important in terms of environment as it avoided the emission of CO_2 from fossil fuel.

The indexes suggested by Copersucar [8] for this activity were adopted, which are as follows: 97% energy sufficiency, 15.62 kWh/tsc electric energy, 11.76 kWh/tsc consumption and the sale of 0.31 kWh/tsc The Sao Jose mill, presented low environmental (C) production at 5 points, as its production of energy is only to satisfy internal demand. The Ester and Santa Elisa mills presented average production (B), both with 9 points each (Table 3).

17. Conclusion

The methodology used, provided a vision of environmental efficiency for the three mills studied. As the concept of environmental efficiency was represented on a numerical scale, it allowed comparisons, in terms of performance, to be made between the mills, their activities and between indicators from mill to mill. Its systematic use allows the evaluation of not only the global tendency but also the tendency for each activity and for each one of the indicators. Thus, it can be seen as a management instrument, which apart from pointing out those activities in more need of attention, sets up objectives and evaluates the consequences from the actions implemented.

Taking as a basis the cases studied; there are some results that seem paradoxical. For example, the application of the liquor and the incorporation of the solid residues in the soil provided economy in fertilizers for the three mills. However, only one of them (the Santa Elisa mill) showed a tendency to reduce the use of chemical fertilizers. In the other two the opposite occurred. There is also no clear relationship between these facts and the productivity of each mill. This indicates that if the data is correct, it will be necessary to establish other connections and check the influence of the variables that were not considered such as: soil components and rain distribution.

Although the development of this methodology was motivated by the necessity to evaluate the production of alcohol as a fuel in Brazil, it can be easily adapted for the evaluation of any agricultural-industrial activity.

The method can be improved in terms of defining different weights for the indicators, as some may influence more than others. The definition of the indicators in Groups 1, 2 and 3 was based on the authors' definitions and sensibility, however this can be discussed more deeply to try and identify the best practices and adopt them as references.

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