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NET ENERGY ANALYSES OF ALCOHOL PRODUCTION
FROM SUGARCANE IN THE CARIRI REGION OF
CEARÁ, BRAZIL

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by

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Preface

The papers included in this series are a result of a collaborative research agreement between the University of Arizona, the Bank of Northeast Brazil, and the Federal University of Ceará. The project, which began in September 1980, is entitled, "Economic and Technical Aspects of Energy Production from the Agricultural Sector in Northeast Brazil. Support for participation by the University of Arizona is provided by the Office of International Cooperation and Development of the U.S. Department of Agriculture. The Brazilian National Research Council (CNPq) is supporting part of the work undertaken by the Federal University of Ceará.

A limited number of these papers are being distributed to researchers and others interested in the economic and technical aspects of energy and agriculture. Working Papers are being published in the language of the authors: English or Portuguese. Contents of the papers represent the opinions and analyses of the authors, not the agencies in which they are employed. Most of the papers in this series are preliminary in nature and are subject to revision. It is expected that some of the papers will be revised and subsequently published as journal articles, monographs, etc. Inquiries and comments should be addressed to:

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NET ENERGY ANALYSES OF ALCOHOL PRODUCTION FROM SUGARCANE IN THE CARIRI REGION OF CEARA, BRAZIL

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Introduction

Before the 1973 oil embargo, cheap petroleum and its easy availability provided a partial and temporary solution to the chronic energy problems faced by most of the developing countries of the world. The overnight trippling of petroleum prices in 1973 adversely affected the economies of most oil importing countries including Brazil which was importing 80-85 percent of its oil requirements (4).

In order to meet the challenge of the new situation provoked by the petroleum crisis as well as to save the sugar industry which was facing low prices in the international market in the early seventies, the Government of Brazil created the National Alcohol Program (PROALCOOL) by decree (Dec. Law. n. 76.593) on the 14th of November 1975. PROALCOOL was designed to reduce external dependence on liquid fuel; to increase national income by the utilization of unused factors of production; to reduce regional and individual income disparities; and to reduce the migratory trend from rural to urban areas and from the north and northeast to central and southern regions of the country (5).

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To achieve a reduction in imported oil, PROALCOOL initially aimed at producing 3 billion liters of alcohol during 1980. To accomplish this goal, the Government of Brazil financed through PROALCOOL the installation of annexed and autonomous distilleries of large capacities mainly in the state of Sao Paulo.[1/] The concentration of distilleries in one state led to the failure of PROALCOOL in achieving most of the goals originally established by the government (3).

During 1979, the Government of Brazil revised its energy policy and set an alcohol production target of 10.7 billion liters in the year 1985. To achieve this goal, PROALCOOL will finance the installation of different capacity distilleries in various sugarcane and manioc growing areas of the country.

The Cariri Region

The Cariri region of the state of Ceará, which is a mixed crop and livestock producing area with sugarcane production in the lower, humid valleys, is a candidate for the installation of small to medium size distilleries designed to meet the overall objectives of PROALCOOL. The Cariri region was selected for this study for the following reasons:

1. Within the state of Ceará, it is one of the major sugarcane producing regions.
2. Sugarcane in the region is produced by traditional methods that are not used in the principal sugarcane producing area of the Northeast (Zona da Mata) nor in the Center-South of Brazil.

1/ Annexed distilleries are those which operate jointly with existing sugar refineries; autonomous distilleries operate independently and produce only alcohol and its by-products.

3. Sugarcane production in the Cariri region is representative of the smaller producing areas of the Northeast that are coming under the influence of PROALCOOL and the introduction of new production technologies.
4. No studies of energy consumption and production exist for the region.

Selection of the Cariri region allowed the authors to focus on three important issues relative to the production and consumption of energy in the agricultural sector of Northeast Brazil. First, it was possible to investigate the energy aspects of two new sugarcane production technologies being proposed for the region. Second, it was possible to consider the sugarcane production technologies in combination with the processing of cane into alcohol as proposed by PROALCOOL. Third, alternative methods of using the by-products of alcohol production (bagasse and stillage) were investigated.

Material and Method

Sugarcane productivity in the state of Ceará is one of the lowest in the nation (37 m.t./ha/yr. compared to 66 m.t. in the state of Sao Paulo), and this situation is attributed to the fact that sugarcane growers, in general, do not use modern agricultural technologies. The para-governmental state and federal agricultural agencies developed and have been recommending since 1977 new semi-mechanized technologies based on intensive use of fertilizers (System I) and on improved cultural practices without chemical fertilizer (System II). System I is expected to produce 80 tons/ha/year of sugarcane and System II 60 tons/ha./year.

The data on physical coefficients of various inputs and associated expected yields for both production systems were obtained from the bulletin entitled, "Sistemas de Produção para Cana-de-Açucar," prepared jointly by federal and state agriculture agencies (14).

Total labor, farm machinery and equipment, fertilizers and insecticides were translated into energy equivalents using the conversion factors reported by Heichel and Conn (7,8), Pimentel, et al. (12), da Silva, et al. (6), and Hopkinson and Day (9), are shown in Table 1. The energy embodied in the distillery machinery was calculated by using the information provided by Birkett and Polack (2), and Hopkinson and Day (9).

The total weights of farm machinery and equipment, excluding hand tools, required for the production of one hectare of first crop sugarcane and its transportation to a distillery under Systems I and II are estimated at 21.58 kg. and 18.79 kg., respectively. These machinery weights were translated into equivalent energy by using the estimated energy input for manufacturing and maintenance of farm machinery as reported by Berry and Fels (1), Pimentel, et al. (12) and Hopkinson and Day (9); they calculated the energy equivalent of 20,691 Kcal/kg for machinery and equipment which functions from 4 to 15 years (9). Maintenance was assumed to be 6 percent of the total machinery energy value (12).

To determine the area for sugar cane production to meet annual feedstock requirements of the distillery, it was assumed that the daily capacity of the distillery is twenty thousand liters. It also was assumed that under System I, 2100 ha. of land will be producing 682 ha. of sugarcane yearly; System II will require 3000 ha. of land to produce about 900 ha. of sugarcane per year.

To calculate the quantity of fuel necessary to transport feedstock, we assumed that the distillery is located in the center of the sugarcane plantation.

Table 1. Energy Conversion Coefficients of Various Inputs and Products

Inputs, Products	Unit	Energy Equivalent (Kcal)
Labor	man-hour	544
Nitrogen (N)	Lb.	8,400
Phosphorus (P)	Lb.	1,520
Potassium (K)	Lb.	1,050
Insecticide	Lb.	11,000
Seed	Kg	102
Diesel oil	1	8,454
Farm machinery and equipment	Kg	20,691
Bagasse	Kg	1,296
Anhydrous alcohol	1	5,260

Source: For labor, nitrogen, phosphorous, potassium, insecticide, see (12); for seed, diesel oil, bagasse, anhydrous alcohol, see (6); and for farm machinery and equipment, see (7, 8, 12).

For industrial ethyl alcohol production, it was assumed that each ton of sugarcane will produce 66 liters of anhydrous alcohol and 250 kg. of bagasse. Each liter of alcohol requires 5.5 kg. of steam and each kg. of bagasse can generate 2.4 kg. of steam or 1296 Kcal (6). The energy requirement for ethanol production from sugarcane includes the energy necessary for feedstock processing, ethanol distillation, and evaporation and drying of stillage, all of which is accomplished with steam generated by burning bagasse. The distillery machinery necessary to produce alcohol from one hectare of sugarcane was translated into its energy equivalents: 604 Mcal and 498 Mcal under System I and System II, respectively (2). The industrial phase of alcohol production is represented in Figure 1.

For part of the analysis, it was assumed that distillery effluent (stillage) would be evaporated and dried in order to use it as one of the components of animal feed. Jenkins, et al. (10) reported that the stillage associated with each Kcal of alcohol requires 0.085 Kcal to transform it into dried distillers grain of energy equivalent to 0.011 Kcal. On the surface, it appears that the conversion of stillage to dried distillers grain is irrational. However, the private and social costs of disposing of large volumes of stillage may force the use of inefficient (in terms of energy) conversion techniques. In this study, results for both conversion and nonconversion of stillage are presented.

In summary, the following hypothetical systems were studied:

System I -- new cultural practices and the use of chemical fertilizer for producing sugarcane.

System II -- new cultural practices without the use of chemical fertilizer for producing sugarcane.

Case 1 -- converting all bagasse to steam and not evaporating and drying the stillage.

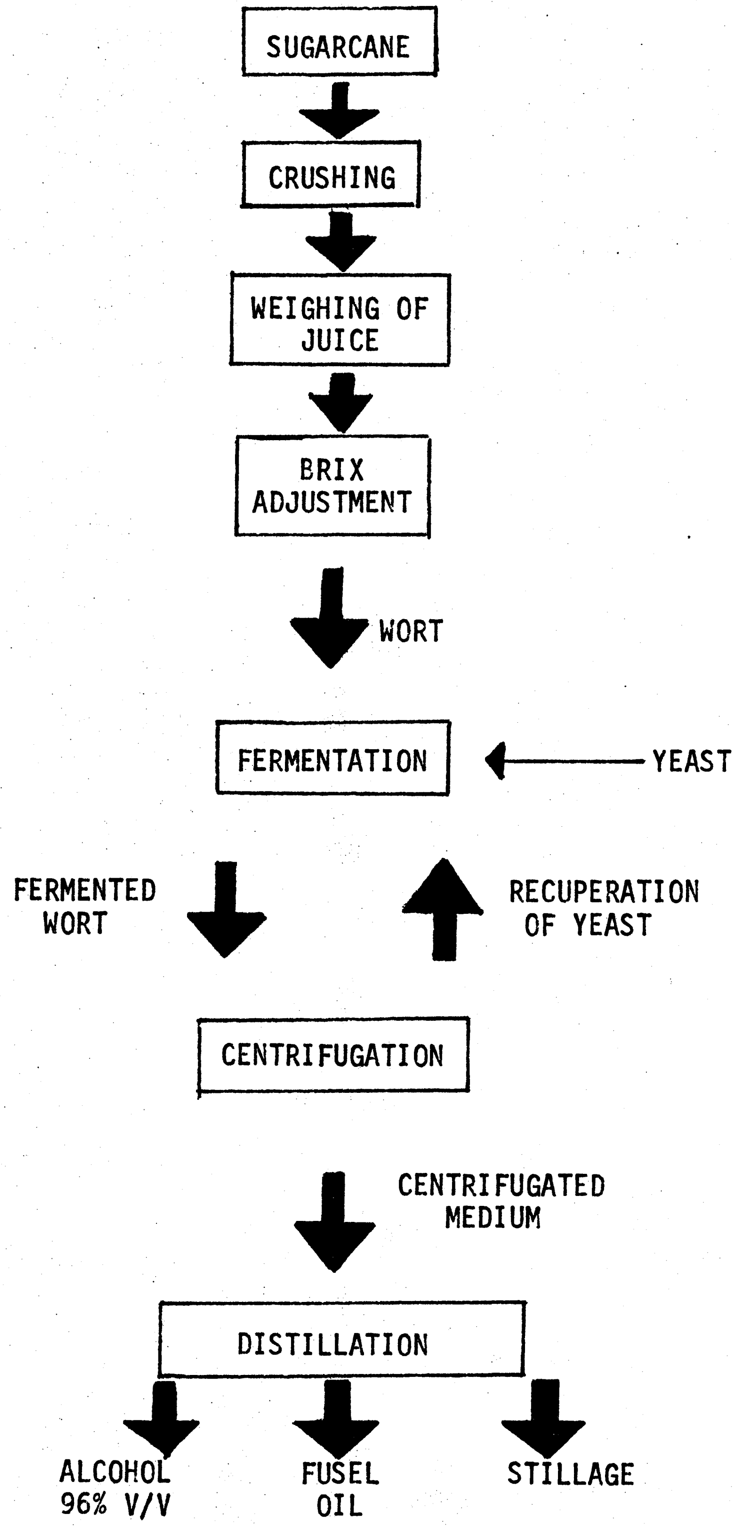

Figure 1. Flow Diagram -- Ethyl Alcohol Distillery

Case 2 -- converting enough bagasse to steam in order to provide process heat for alcohol production.

Case 3 -- converting all bagasse to steam and also transforming the stillage into dried distillers grain.

Case 4 -- converting enough bagasse to steam in order to provide heat for alcohol production and for evaporation and drying of stillage.

Results and Discussion

The energy analysis considered the total system inputs. These included energy to grow feedstock, energy to produce fertilizer and insecticide; energy to manufacture machinery to grow and transport feedstock to a distillery; energy needed to manufacture industrial machinery to process sugarcane into ethanol; and energy consumed to transform stillage, a by-product, into dried distillers grain (animal feed). This approach differs from the energy analyses performed in many other studies (6,9,13) which did not include the energy embodied in the industrial machinery used in ethyl alcohol production or did not consider the treatment of stillage.

Sugarcane Production and Transportation

The energy requirements to grow, harvest and transport sugarcane to a distillery under both Systems in the Cariri region and for three crops, i.e., first crop, first ratoon and second ratoon are shown in Table 2 and Table 3. More detailed information on the physical coefficients used in these systems is given in Appendix Tables I to VIII. The energy expended on machinery also includes the energy equivalent of hand tools, such as axes and hoes used to perform some of the manual agricultural operations. The fuel estimate includes the quantity of diesel oil consumed in the agricultural phase

Table 2 Energy Expended in the Production and Transportation of One Hectare of Sugarcane in the Cariri Region of Ceará, Brazil--System I

Inputs	First Crop		First-ratoon		Second-ratoon		Total	Average	
	Kcal	Percentage	Kcal	Percentage	Kcal	Percentage	Kcal	Kcal	Percent
Labor*	937,682	17.96	715,686	22.63	715,686	22.63	2,369,054	789,684	20.51
Machinery+	465,502	8.92	341,418	10.79	341,418	10.79	1,148,338	382,779	9.94
Seed	816,377	15.63	--	--	--	--	816,377	272,126	7.07
Insecticides	48,889	0.94	--	--	--	--	48,889	16,296	0.42
Fuel	1,219,320	23.35	816,402	25.81	816,402	25.81	2,852,124	950,708	24.70
Nitrogen	1,530,667	29.31	1,148,000	36.29	1,148,000	36.29	3,826,667	1,275,556	33.14
Phosphorus	86,809	1.66	60,091	1.90	60,091	1.90	206,991	68,997	1.79
Potassium	116,667	2.23	81,667	2.58	81,667	2.58	280,001	93,334	2.43
Total	5,221,913	100.00	3,163,264	100.00	3,163,264	100.00	11,548,441	3,849,480	100.00

* Includes labor for irrigation and transportation to a distillery.
+ Energy expended on machinery includes 2,420 Kcal energy equivalent of 8 hours use of a hand sprayer to spray insecticides on the first crop, and 16,570 Kcal energy equivalents for ax and manual hoe are included in the calculation for all three crops. Also includes machinery for transportation to a distillery.

Table 3. Energy Expended in the Production and Transportation of One Hectare of Sugarcane in the Cariri Region of Ceará, Brazil--System II

Inputs	Plant Cane		First-ratoon		Second-ratoon		Total	Average	
	Kcal	Percentage	Kcal	Percentage	Kcal	Percentage	Kcal	Kcal	Percent
Labor*	858,606	26.18	645,315	38.56	645,315	38.56	2,149,236	716,412	32.43
Machinery+	407,774	12.44	283,691	16.95	283,691	16.95	975,156	325,052	14.72
Seed	816,377	24.90	--	--	--	--	816,377	272,126	12.32
Insecticides	48,889	1.49	--	--	--	--	48,889	16,296	0.74
Fuel	1,147,377	34.99	744,459	44.49	744,459	44.49	2,636,295	878,765	39.79
Total	3,279,023	100.00	1,673,465	100.00	1,673,465	100.00	6,625,953	2,208,651	100.00

* Includes labor for transportation to a distillery and for irrigation.
+ Energy expended on machinery includes 2,420 Kcal energy equivalent of 8 hours use of a hand sprayer to spray insecticide on the first crop, and 16,570 Kcal energy equivalents for ax and manual hoe are included in the calculation for all three crops. Also includes machinery for transportation to a distillery.

of sugarcane production and its transportation to a distillery.

Table 4 provides a comparison between the two different production and transportation systems. One hectare of sugarcane production and transportation requires about 74 percent more energy under System I than under System II. The single largest energy input in sugarcane production is fertilizer; nitrogen alone accounts for more than 33 percent and fertilizer as a whole stands for about 37 percent of the total energy consumption. The high energy input from fertilizer use might be brought down by replacing fertilizer with animal manure; however, the use of manure was not investigated in this study. Fuel takes second place, followed by labor. In System II, fuel and labor occupy the first and second places.

The energy input for insecticides in sugar cane production under both systems is the same and the smallest of all inputs, about 16,000 Kcal. The machinery share of total energy consumption is substantially lower than reported in most other studies (6,9,12,12). This results from performing some of the agricultural operations by manual labor and hand tools rather than relying heavily on mechanization. However, total energy consumed by System I in the agricultural phase is the same as that calculated by daSilva in Sao Paulc (6).

Alcohol Production

The total energy expended in the manufacture of distillery machinery depends on the distillery capacity and the technology used in the conversion of feedstock to ethyl alcohol. The distillery machinery equivalent of 604 Mcal and 498 Mcal is required to process one hectare of sugarcane under Systems I and II, respectively (Table 5). In addition, large amounts of energy are used to provide process heat for the industrial phase, with System I using about 4,000 more Mcal/ha./year than System II (Table 5). For Cases 3 and 4,

Table 4 Summary of Energy Expended in the Production and Transportation of One Hectare of Sugarcane in the Cariri Region of Ceará, Brazil: Systems I and II.*

Inputs	System I (Expected yield--80 ton/ha/year)		System II (Expected yield--60t/ha/year)	
	Kcal	Percent	Kcal	Percent
Labor	789,684	20.51	716,412	32.43
Machinery	382,779	9.94	325,052	14.72
Seed	272,126	7.07	272,126	12.32
Insecticides	16,296	0.42	16,296	0.74
Combustibles	950,708	24.70	878,765	39.79
Nitrogen	1,275,556	33.14	--	--
Phosphorus	68,997	1.79	--	--
Potassium	93,334	2.43	--	--
Total	3,849,480	100.00	2,208,651	100.00

* See Tables 2 and 3 for details.

Table 5. The Energy Output-Input Ratio of Alcohol Production from Sugarcane in the Cariri Region of Ceará, Brazil.

System	Case*	Agricultural Yield (ton/ha/year)	Alcohol Production		Energy Produced (Mcal/ha/year)				Energy Expended (Mcal/ha/year)						Energy Ration (Produced/Consumed)
										Industry					
			Liters/ ton	Liters/ Hectare	Alcohol	Bagasse	Dried Distillers Grain (Animal feed)	Total	Agriculture	Industrial Structure	Process heat for Alcohol	Evaporation and Drying of Stillage	Sub-Total	Total	
I	1	80	66	5,280	27,772.8	25,920.0	---	53,692.8	3,849.5	604.0	15,681.6	---	16,285.6	20,135.1	2.67
	2	80	66	5,280	27,772.8	15,681.0	---	43,454.4	3,849.5	604.0	15,681.6	---	16,285.6	20,135.1	2.16
	3	80	66	5,280	27,772.8	25,920.0	294.0	53,986.8	3,849.5	604.0	15,681.6	2,360.7	18,646.3	22,495.8	2.40
	4	80	66	5,280	27,772.8	18,042.3	294.0	46,109.1	3,849.5	604.0	15,681.6	2,360.7	18,646.3	22,495.8	2.05
II	1	60	66	3,960	20,829.6	19,440.0	---	40,269.6	2,208.6	498.0	11,761.2	---	12,259.2	14,467.8	2.78
	2	60	66	3,960	20,829.6	11,761.2	---	32,590.8	2,208.6	498.0	11,761.2	---	12,259.2	14,467.8	2.25
	3	60	66	3,960	20,829.6	19,440.0	220.5	40,490.1	2,208.6	498.0	11,761.2	1,770.5	14,029.7	16,238.3	2.49
	4	60	66	3,960	20,829.6	13,531.7	220.5	34,581.8	2,208.6	498.0	11,761.2	1,770.5	14,029.7	16,238.3	2.13

* Case 1 -- Converting all bagasse to steam and not evaporating and drying the stillage.
Case 2 -- Converting enough bagasse to steam in order to provide process heat for alcohol production.
Case 3 -- Converting all bagasse to steam and also transforming the stillage into dried distillers grain (D.D.G.).
Case 4 -- Converting enough bagasse to steam in order to provide process heat for alcohol production and for evaporation and drying of stillage.

which include the treatment of stillage, about 2,400 and 1,800 Mcal of additional energy is expended by Systems I and II, respectively.

Overall Energy Balance

Table 5 also provides information on the energy balance for both systems, depicting total energy expended (agricultural and industrial phases), the energy produced, and the energy ratio. The energy consumed by the industrial phase is 4.23 to 4.84 and 5.55 to 6.35 times higher than that in the agricultural phase under Systems I and II, respectively, depending on the treatment of stillage and the conversion of bagasse to steam.

Case 1 of System II has the highest output-input ratio, 2.78, indicating a high return on energy investment. The energy output calculations include the energy that can be obtained by burning all bagasse and not treating the stillage. There is an excess of energy, but it is unlikely that this excess could be economically exported from an alcohol plant to another location (e.g., other processing plant). However, it might be possible to integrate another process with the distillery at the same location (e.g., pumping irrigation water).

Jenkins, et al. (10) reported that adoption of the Tilby process to separate sugar from bagasse without the conventional crushing and maceration would reduce energy consumption in the industrial phase. But this process would leave more bagasse which, at the present time, may not be an exportable form of energy.

The information given in Table 5 also reveals that all four cases under both Systems have an output-input ratio greater than 2. The processes of evaporation and drying of stillage consumed at least 8 times more energy than obtained from the dried distillers grain.

Limitations and Conclusions

Energy analysis of the type presented in this paper is subject to several limitations. First, the results should not be immediately extended to other producing regions without careful consideration of the differences in sugarcane production technologies. Once the differences have been identified and quantified, it is fairly easy to adjust the analyses reported in this paper to reflect different cultural practices and resource productivities. Second, the study is limited by the inability to compare the two new production technologies with the existing traditional methods of producing sugarcane in the Cariri region. Such a comparison was not possible because of the lack of input-output data for the traditional system. Third, because of lack of data, we were unable to estimate the energy needed to dispose of the stillage under Cases 1 and 2. Consequently, although Cases 3 and 4 use more energy, the comparisons are incomplete. Fourth, no economic analyses were performed on the system alternatives. Thus, the results do not provide adequate criteria for selecting the "best" alternative. However, the data presented in this paper are essential to performance of economic analyses, and it is expected that they will be used for this purpose during the later stages of the project.

The results indicate that System I (use of chemical fertilizer) and System II (no chemical fertilizer) are almost equally efficient in terms of the energy ratio. Within the contexts of risk aversion and broader economic considerations, System II may be preferred. The omission of fertilizer reduces economic risks, particularly in drought prone areas such as found in parts of Northeast Brazil. Also, omitting fertilizer might be attractive from the point of view of reducing fertilizer imports and saving scare resources.

Overall, the analysis confirmed the findings of da Silva, et al. (6), that sugarcane can be used as an energy efficient feedstock for ethanol production in Brazil. Moreover, this study extends da Silva's findings to include producing areas (e.g., the Cariri Region of Ceará) that use more traditional production technologies.

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Appendix Table I. Cultural Practices and Inputs Used to Cultivate One Hectare of Sugarcane. (Expected Yield of 80 mt/year) in the Cariri Region of Ceará, Brazil--First Crop Year (System I)

Items	Labor	Tractor Driver	Tractor	Plough	Harrow	Cultivator	Hand Sprayer	Manual Hoe	Cart
A. Land Preparation and Planting	Days of Service (8 hours/day)								
1. Ploughing	--	0.50	0.50	0.50	--	--	--	--	--
2. Breaking of clods and removing roots	2.0	--	--	--	--	--	--	--	--
3. Harrowing	--	0.38	0.38	--	0.38	--	--	--	--
4. Furrowing	--	0.38	0.38	--	--	0.38	--	--	--
5. Cutting and transportation of stalks (for seed)	6.0	--	--	--	--	--	--	--	--
6. Preparing transplants (sets)	8.0	--	--	--	--	--	--	--	--
7. Transplanting	5.0	--	--	--	--	--	--	--	--
8. Covering the transplants	11.0	--	--	--	--	--	--	--	--
B. Cultural Practices and Harvesting									
1. Hoeing (4 times)	63.0	--	--	--	--	--	--	63.0	--
2. Application of fertilizer (2 times--before and after planting)	5.0	--	--	--	--	--	--	--	--
3. Irrigation	33.0	--	--	--	--	--	--	--	--
4. Application of insecticides	1.0	--	--	--	--	--	1.0	--	--
5. Harvesting[a/]	54.0	--	--	--	--	--	--	--	--

Appendix Table I (Continued)

Items	Labor	Tractor Driver	Tractor	Plough	Harrow	Cultivator	Hand Sprayer	Manual Hoe	Cart
6. Loading and transportation to distillery	26.0	1.20	1.20	--	--	--	--	--	3.7
Sub-Total	214.0	2.56	2.46	0.50	0.38	0.38	1.0	63.0	3.7

C. Material Used (Inputs)

1. Diesel oil plus lubrication oil[b/] = 144.23 l
2. Seed = 8 t
3. Insecticides = 2 kg
4. Fertilizers
   - i. Amonium Sulphate = 400 kg
   - ii. Triple Super Phosphate = 130 kg
   - iii. Potassium Chloride = 100 kg

[a/] Based on 1.5 tons/man day

[b/] On the average, a tractor of 80 hp consumes 5.28 liters/hours to perform various cultural operations; the average speed of the cart is 20 km/hour; the capacity of cart is 2 tons; average round trip distance from sugarcane fields to distilling is 4.58 km; cart driven by tractor covers 2.13 km/liter to transport sugarcane.

Source: (14)

Appendix Table II. Cultural Practices and Inputs Used to Cultivate One Hectare of Sugarcane. (Expected Yield of 80 mt/year) in the Cariri Region of Ceará, Brazil--First Ratoon (System I)[a]

Items	Labor	Tractor Driver	Tractor	Plough	Harrow	Cultivator	Hand Sprayer	Manual Hoe	Cart
A. Cultural Practices and Harvesting	Days of Service (8 hours/day)								
1. Irrigation	25.0	--	--	--	--	--	--	--	--
2. Mulching	5.0	--	--	--	--	--	--	--	--
3. Cleaning and burning of crop residue	2.0	--	--	--	--	--	--	--	--
4. Cutting and removal of old stalks	4.0	--	--	--	--	--	--	--	--
5. Scarifying	--	0.25	0.25	--	--	0.25	--	--	--
6. Hoeing (3 times)	45.0	--	--	--	--	--	--	45.0	--
7. Application of fertilizer	2.0	--	--	--	--	--	--	--	--
8. Harvesting[b]	54.0	--	--	--	--	--	--	--	--
9. Loading and transportation to distillery	26.0	1.20	1.20	--	--	--	--	--	3.7
Sub-Total	163.0	1.45	1.45	--	--	0.25	--	45.0	3.7

B. Material Used (Inputs)

1. Diesel oil plus lubrication oil[c] = 96.57 l

2. Fertilizers

   i. Amonium Sulphate = 300 kg

Appendix Table II (Continued)

2. Fertilizers (continued)

   ii. Triple Super Phosphate = 90 kg

   iii. Potassium Chloride = 70 kg

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a/ Similar table can be constructed for second ratoon

b/ Based on 1.5 tons/man-day

c/ See footnote b/ of Appendix Table I

Source: (14)

Appendix Table III. Energy Cost of Cane Production (First Crop) in the Cariri Region of Ceará, Brazil--System I

Inputs	Unit	Amount (Per ha.)	Energy Expended (Kcal/ha.)	Percent of Total
Labor	Man-day	215.46	937,682	17.96
Machinery[a]	kg	21.58	465,502	8.92
Seed	t	8.00	816,377	15.63
Diesel oil	l	144.23	1,219,320	23.35
Insecticides	kg	2.00	48,889	0.94
Amonium Sulphate	kg	400.00	1,530,667	29.31
Triple Super Phosphate	kg	130.00	86,809	1.66
Potassium Chloride	kg	100.00	116,667	2.23
Totals			5,221,913	100.00

[a] Energy expended on machinery includes 2,420 Kcal energy equivalent of 8 hours use of hand sprayer and 16,570 Kcal energy equivalent for ax and manual hoe to perform crop operations. It also includes transportation to a distillery.

Source: For amount per hectare (14) and for energy expended (6,7,8,12).

Appendix Table IV. Energy Cost of First-Ratoon Sugarcane Production in the Cariri Region of Ceará, Brazil--System I

Inputs	Unit	Amount (Per ha.)	Energy Expended (Per ha.)	Percent of Total
Labor	Man-day	164.45	715,686	22.63
Machinery[a]	kg	15.70	341,418	10.79
Diesel oil	l	96.57	816,402	25.81
Amonium Sulphate	kg	300.00	1,148,000	36.29
Triple Super Phosphate	kg	90.00	60,091	1.90
Potassium Chloride	kg	70.00	81,667	2.58
Totals			3,163,264	100.00

[a]Energy expended on machinery includes 16,570 Kcal energy equivalent for the use of ax and manual hoe in the production of the crop.

Source: Appendix Table III.

Appendix Table V. Cultural Practices and Inputs Used to Cultivate One Hectare of Sugarcane. (Expected Yield of 60 mt/year) in the Cariri Region of Ceará, Brazil--First Crop Year (System II).

Items	Labor	Tractor Driver	Tractor	Plough	Harrow	Cultivator	Hand Sprayer	Manual Hoe	Cart
A. Land Preparation and Planting				Days of Service (8 hours/day)					
1. Ploughing	--	0.50	0.50	0.50	--	--	--	--	--
2. Breaking of clods and removing roots	2.0	--	--	--	--	--	--	--	--
3. Harrowing	--	0.38	0.38	--	0.38	--	--	--	--
4. Furrowing	--	0.38	0.38	--	--	0.38	--	--	--
5. Cutting and transportation of stalks (for seed)	6.0	--	--	--	--	--	--	--	--
6. Preparing transplants (sets)	8.0	--	--	--	--	--	--	--	--
7. Transplanting	5.0	--	--	--	--	--	--	--	--
8. Covering the transplants	11.0	--	--	--	--	--	--	--	--
B. Cultural Practices and Harvesting									
1. Hoeing (4 times)	63.0	--	--	--	--	--	--	63.0	--
2. Application of insecticides	1.0	--	--	--	--	--	1.0	--	--
3. Irrigation	33.0	--	--	--	--	--	--	--	--
4. Harvesting[a/]	40.0	--	--	--	--	--	--	--	--
5. Loading and transportation to distillery	26.0	1.03	1.03	--	--	--	--	--	2.91
Sub-Total	195.0	2.29	2.29	0.50	0.38	0.38	1.0	63.0	2.91

Appendix Table V (Continued)

C. Material Used (Inputs)

1. Diesel oil plus lubrication oil[b/] = 135.72 l

2. Seed = 8 t

3. Insecticide = 2 kg

[a/]See footnote a/ Appendix Table 1

[b/]On the average, a tractor of 80 hp burns 5.28 liters/hours to perform various cultural operations; covers 2.13 km/liter with an average speed of 20 km/hour. The capacity of cart is 2 tons and average round trip distance from sugarcane fields to the distillery is 5.5 km.

Source: (14)

Appendix Table VI. Cultural Practices and Inputs Used to Cultivate One Hectare of Sugarcane. (Expected Yield of 60 mt/year) in the Cariri Region of Ceará, Brazil--First Ratoon Crop (System II)[a]

Items	Labor	Tractor Driver	Tractor	Plough	Harrow	Cultivator	Hand Sprayer	Manual Hoe	Cart
A. Cultural Practices and Harvesting	Days of Service (8 hours/day)								
1. Irrigation	25.0	--	--	--	--	--	--	--	--
2. Mulching	5.0	--	--	--	--	--	--	--	--
3. Cleaning and burning of crop residue	2.0	--	--	--	--	--	--	--	--
4. Cutting and removal of old stalks	4.0	--	--	--	--	--	--	--	--
5. Scarifying	--	0.25	0.25	--	--	0.25	--	--	--
6. Hoeing (3 times)	45.0	--	--	--	--	--	--	45.0	--
7. Harvesting[b]	40.0	--	--	--	--	--	--	--	--
8. Loading and transportation to distillery	26.0	1.03	1.03	--	--	--	--	--	2.91
Sub-Total	147.0	1.28	1.28	--	--	0.25	--	45.0	2.91

B. Material Used (Inputs)

1. Diesel oil plus lubrication oil[c] = 88.06 l

[a]Similar table can be constructed for Second Ratoon

[b]See footnote a/ Appendix Table I

[c]See footnote b/ Appendix Table V

Source: (14)

Appendix Table VII. Energy Cost of Cane Production (First Crop) in the Cariri Region of Ceará, Brazil--System II

	Unit	Amount (Per ha.)	Energy Expended (Kcal/ha.)	Percent of Total
Labor	Man-day	197.29	858,606	26.18
Machinery[a/]	kg	18.79	407,774	12.44
Seed	t	8.00	816,377	24.90
Diesel oil	1	135.72	1,147,377	34.99
Insecticide	kg	2.00	48,889	1.49
Totals			3,279,023	100.00

[a/] See footnote a/ Appendix Table III.

Source: Appendix Table III

Appendix Table VIII. Energy Cost of First Ratoon of Sugarcane in the Cariri Region of Ceará, Brazil--System II

	Unit	Amount (Per ha.)	Energy Expended (Kcal/ha.)	Percent of Total
Labor	Man-day	148.28	645,315	38.56
Machinery[a/]	kg	12.91	283,691	16.95
Diesel oil	1	88.06	744,459	44.49
Totals			1,673,465	100.00

[a/] See footnote a/ of Appendix Table IV.

Source: Appendix Table III.