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Energy Assessment for First and Second Season Conventional and Transgenic Corn

Rodolfo Michelassi Silber and Thiago Libório Romanelli *

Department of Biosystems Engineering, Luiz de Queiroz College of Agriculture, University of Sao Paulo/ESALQ, C.P., Piracicaba 09-13418-900, SP, Brazil; rodolfosilber@usp.br
* Correspondence: romanelli@usp.br

Abstract: The exploitation of natural resources for agriculture is growing to fulfill the demand for food, which requires the rational use of inputs for sustainable production. Brazilian agricultural production stands out on the international scene. For instance, corn is one of the most exported products in Brazil, which is possible through the planting in the second crop season within a year, called the "off-season". In addition to being a technique that allows soil conservation, it also reduces the use of inputs and soil tillage. The agricultural production systems require a large amount of energy throughout their processes, mainly through inputs and fuels. Energy flows allow for the identification of the efficiency of the production system and, consequently, its sustainability. Indicators regarding net energy gain per area (Energy balance) and energy profitability (Energy Return on Investment) were applied. The first-season system presented higher energy demand when compared to the second-season system, with a difference of 10.24 GJ ha^{-1} between the conventional ones and 10.47 GJ ha^{-1} between the transgenic ones. However, the indicators showed higher energy efficiency in the transgenic off-season corn production, in which the return on energy was 55% higher, and the energy incorporation was 35% lower when compared to conventional first-season corn.

Keywords: energy balance; *Zea mays*; sustainability

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1. Introduction

Modern agriculture requires the exploitation of natural resources to fulfill the growing demand for food and energy, especially driven by rising incomes in developing countries and population growth. Therefore, it is necessary to conserve and manage natural resources through the higher efficiency of input use and sustainable agriculture, to supply current human needs and those of future generations [1].

Brazil stands out in the global scenario as one of the largest agricultural producers; corn production is a significant part of its agriculture. The possibility of cultivating corn in the second "off-season" crop season within a single year allows Brazil to have an increased grain production and stand out in the international market. In addition to making it possible to carry out two crops in the same year, this technique contributes to soil management and conservation, taking advantage of the inputs and tillage made for the main crop [2].

In 2021, Brazil was the third-largest producer (8%), behind the United States (32%) and China (23%) of world corn production. In that season, corn crops in Brazil were affected by weather constraints, presenting a reduction of 15% compared to 2020 [3].

Agriculture has high energy demands, mainly from non-renewable sources, such as fossil fuels, fertilizers, and pesticides, which are necessary for current production systems, making it possible to explore the crop yield potential. In this way, the energy flow evaluation makes it possible to identify the production process that requires less energy for agricultural production. Through the input energy and the output energy (product obtained), it is possible to determine the energy balance (net energy gain) and the ratio between the output and input energy (Energy Return on Investment—EROI), indicating the energy profitability [4].

Although more recent approaches for energy analysis have been conducted, such as the water–energy–food nexus [5], the exergy of biomass production [6], and decision support systems [7], the traditional indicators presented have been widely used for the energy efficiency assessment of agricultural production systems.

Thus, identifying more energy-efficient production systems indicates the sustainability of agricultural products, reducing the negative environmental effects of anthropogenic origin. Thus, this study aims to analyze the energy efficiency of different corn production systems and compare their energy efficiency.

2. Materials and Methods

The data relating to the corn production systems—first- and off-season—were obtained from [8]. This reference provides information regarding the production cost of different crops throughout distinct regions of Brazil.

For both systems (first and off-season), data considering crops of either conventional or transgenic corn were obtained. Therefore, for first-season corn, the states of Paraná (PR), Rio Grande do Sul (RS), and Santa Catarina (SC) were selected, and for the off-season corn, the states of Mato Grosso do Sul (MS), Mato Grosso (MT) and Paraná (PR) between 2009/10 and 2019/20 were selected, as they represent the main producing states in the country for the respective producing season [9].

The material flows obtained through the database allowed the energy flows of the different production systems to be determined through the incorporated energy of each input [10]. Thus, Table 1 provides the values for each entry, as well as its reference.

Table 1. Energy index for directly applied inputs.

Input	Unit	Energy Index(MJ unit^{-1})	References
N	kg	66.98	[11]
P_2O_5	kg	17.39	[12]
K_2O	kg	13.64	[12]
Lime	kg	1.17	[13]
Corn seeds	kg	103.96	[14]
Herbicides	l	418.68	[15]
Insecticides	l	310.35	[16]
Fungicides	l	271.77	[10]
Others	kg	205.24	[10]
Maize	kg	14.58	[10]
Diesel	l	47.73	[15]
Labor	h	2.46	[17]
Machinery depreciation	kg	76.10	[18]

To determine the energy flows, the operations and inputs were grouped into: (A) operations (A.1. soil conservation, A.2. soil tillage, A.3. seeding, A.4. crop protection, and A.5. harvest), and B) inputs (B.1 fertilizers and limestone, B.2. seeds and sowing material, and B.3. pesticides).

The energy required by the operations is composed of the depreciation of machinery (Equation (1)) [19], fuel consumption (Equation (2)) [20], and labor (Equation (3)) [21], and their sum results are the indirect energy inputs (EEi). Therefore, the sum of the energy incorporated in the inputs (fertilizers, seeds, pesticides, etc.) resulted in the direct energy inputs (EEd).

$$\mathrm{MD} = \sum_{i=1}^{I} \frac{\left[\left(\frac{\mathrm{Mtr}}{\mathrm{ULtr}} + \frac{\mathrm{Mimp}}{\mathrm{ULimp}}\right)\mathrm{index}_{\mathrm{MACH}}\right]_{\mathrm{i}}}{\mathrm{FCi}} \quad (1)$$

where MD (MJ ha^{-1}) is the depreciation of machines and implements; Mtr (kg) is the mass of the tractor; Mimp (kg) is the mass of the implements; ULtr (h) is the useful life of the tractor; ULimp (h) is the useful life of the implements; Index$_{\mathrm{MACH}}$ (MJ kg^{-1}) is the energy incorporated into agricultural machinery; FCi (ha h^{-1}) is the operational field capacity of the ith operation.

$$\text{Cons} = \sum_{i=1}^{I} \frac{[(\text{Pow} * \text{SC})\text{index}_{\text{FUEL}}]_{\text{i}}}{\text{FCi}} \quad (2)$$

where Cons (MJ ha^{-1}) is the fuel consumption; Pow (kW) is the engine power; SC (0.167 L kW^{-1} h^{-1}) is the specific consumption; $\text{Index}_{\text{FUEL}}$ (MJ L^{-1}) is the incorporated energy in the fuel.

$$\text{Lb} = \sum_{i=1}^{I} \frac{\text{index}_{\text{LBi}}}{\text{FCi}} \quad (3)$$

where Lb (MJ ha^{-1}) is the energy from labor; $\text{Index}_{\text{LBi}}$ (MJ h^{-1}) is the incorporated energy in the labor.

The sum of the direct and indirect energy results in the input energy (IE), establishing and developing the culture. Based on crop yield (Prod), the output energy (OE) is determined, being the energy incorporated in the marketable product. Through yield and the inputs and power outputs, it is possible to obtain indicators such as energy balance (Equation (4)), energy return on investment (Equation (5)), and energy merger (Equation (6)).

$$\text{EB} = \text{OE} - \text{IE} \quad (4)$$

where EB (MJ ha^{-1}) is the energy balance; OE (MJ ha^{-1}) is the output energy; IE (MJ ha^{-1}) is the input energy.

$$\text{EROI} = \text{OE}/\text{IE} \quad (5)$$

where EROI (dimensionless) is the energy return on investment.

$$\text{EE} = \text{IE}/\text{Prod} \quad (6)$$

where EE (MJ t^{-1}) is the embodied energy; Prod (t ha^{-1}) is the crop yield.

An analysis of variance (ANOVA) was performed ($p < 0.05$), for the comparison of the means test by Tukey at 5% significance. The data were analyzed with Minitab® 20 Statistical Software [22].

3. Results

Input energy differed between the first- and off-season production systems but did not differ between conventional and transgenic within the same season (Table 2). This observation is valid for IE and its components, IEi and IEd. The difference between the highest and the lowest IE was 10.64 GJ ha $^{-1.}$ For first-season corn, the conventional crop was less than 1% higher than transgenic. However, the OE presented by the transgenic was 16% higher than the conventional system. For off-season corn, the conventional crop was 2.5% higher than the transgenic system. The OE presented similar behavior to the conventional crop, with transgenic being 15% higher than conventional. The first-season system presented an energy demand (IE) 65% higher than that of the off-season; on the other hand, it presented an OE that was 22.5% higher. For OE, the difference between the highest (The conventional first-season) and lowest (conventional off-season) was 36.94 GJ ha^{-1}, a value higher than any IE determined.

Table 3 presents the energy indicators based on energy input and output [23], allowing us to compare the efficiency of the different systems. On average, transgenic crops presented 20% more net energy gain per area (EB) than conventional ones. Transgenic first-season corn differed from conventional corn in both seasons.

Table 2. Comparison of inputs and outputs of first and second crop corn, conventional and transgenic.

Season	Type	N	IEi	IEd	IE	OE
			(GJ ha^{-1})			
First	Conventional	33	2.83 a	23.65 a	26.49 a	108.60 b
	Transgenic	33	2.74 a	23.58 a	26.32 a	126.12 a
Off	Conventional	33	2.12 b	14.12 b	16.25 b	89.18 c
	Transgenic	33	2.03 b	13.81 b	15.85 b	102.49 bc
	p-Value		0.000	0.000	0.000	0.000

Means followed by the same lowercase letter in the columns do not differ statistically by Tukey's test with 95% confidence. *p*-value indicates error probability when stating that there is a difference by the F test.

Table 3. Comparison of first and second season, conventional, and transgenic corn indicators.

Season	Type	N	EB	EROI	EE
			(GJ ha^{-1})	(-)	(GJ t^{-1})
First	Conventional	33	82.11 b	4.19 c	3.74 a
	Transgenic	33	99.80 a	4.89 bc	3.22 b
Off	Conventional	33	72.93 b	5.51 b	2.78 bc
	Transgenic	33	86.64 ab	6.49 a	2.41 c
	p-Value		0.000	0.000	0.000

Means followed by the same lowercase letter in the columns do not differ statistically by Tukey's test with 95% confidence. *p*-value indicates error probability when stating that there is a difference by the F test.

On the other hand, when energy profitability was considered (EROI), the off-season presented a 32% higher efficiency than the first. Transgenic crops were 17% more efficient than conventional crops. Regarding energy efficiency through EROI, transgenic off-season differed from conventional off-season corn (+18%) and both first season crops: transgenic (+33%) and conventional (+55%).

The embodied energy in corn produced presented a similar behavior to the EROI. However, from this point of view, the smaller the value, the better, indicating less energy required per mass. Off-season crops required only 75% of the energy required by first-season crops per tonne of corn. Regarding the genetic material, the transgenic system used 86% of the energy required by the conventional system. The transgenic off-season system differed from all other production systems, saving energy from 13% (conventional off-season) to 36% (first-season conventional).

The composition of the energy demand for the production systems is shown in Table 4. The largest energy expenditure was on inputs, which made up 89% and 90% of inputs for conventional and transgenic first-season corn and 87% for off-season corn. The second-largest demand for energy was fuel, which made up 10% and 9% for conventional and transgenic season corn and 12% and 11% for conventional and transgenic off-season corn.

Table 4. Share of energy inputs for conventional and transgenic first and second season corn.

	First Season		Off Season	
	Conventional	Transgenic	Conventional	Transgenic
Indirect Energy Input				
Depreciation	1%	1%	1%	1%
Labor	-	-	-	-
Diesel	10%	9%	12%	11%
Direct Energy Input				
Inputs	89%	90%	87%	87%

- <0.05%.

The share of depreciation for machines, implements, and labor were <1% for both systems presented. These findings corroborate [24], which has already mentioned that these components could be disregarded.

Table 5 presents the composition of energy inputs, divided into indirect (A) and direct (B) energy inputs. Among the operations, the biggest participations were sowing, crop protection, and harvesting. Off-season corn does not require soil tillage [2].

Table 5. Shares of operations and inputs in energy demand for conventional and transgenic corn of the first and off season.

	First Season		Off Season	
	Conventional	Transgenic	Conventional	Transgenic
A.1. Soil conservation	1%	1%	1%	1%
A.2. Soil tillage	1%	1%	-	-
A.3. Seeding	2%	2%	3%	3%
A.3. Cultivation	4%	4%	4%	3%
A.4. Harvest	3%	3%	5%	5%
Subtotal A	11%	10%	13%	13%
B.1. Fertilizers/Lime	65%	66%	55%	55%
B.2. Seeds/Mat. Planting	9%	8%	14%	14%
B.3. Pesticides	16%	15%	19%	18%
Subtotal B	89%	90%	87%	87%

Among the inputs, in both cases, fertilizers and lime corresponded with the highest share, followed by pesticides and seeds and sowing material. The latter presented a higher share for off-season than first-season crop.

Thus, the production system used by producers in first and off-season corn presents a high energy demand for fertilizers and pesticides and, due to agricultural mechanization, fuel. Future research can assess energy efficiency in the use of biological alternatives for fertilization and plant protection, in addition to the adoption of technologies such as variable rate application for fertilizers and seeds in order to assess the sustainability of agricultural production systems.

4. Conclusions

The first-season corn production system presented the highest input energy demand when compared to the off-season. Among the indicators, considering EROI and Embodied Energy (MJ t^{-1}), the transgenic corn off-season was the most efficient and the conventional first season the least efficient. Fertilizers and lime had the highest share in energy inputs, followed by pesticides in both cases.

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