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Energy balance of biodiesel production from canola

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ABSTRACT: *The aim of the present study was to estimate the energy balance (output/input ratio) of the canola crop for biodiesel production, under Brazilian conditions. Fossil energy expended in the production of 600kg of oil per hectare was 7,146,537kcal. The estimated energy yield per hectare was 9,930,000kcal from the production of 1,500kg ha⁻¹ of seeds (40% oil and 60% oil cake), which resulted in an energy balance of 1.39. Results indicated the viability of biofuel production from canola, but also showed the need to improve the technology used to increase the energy and economic balance ratios.*

Key words: *Brassica napus* L. var. *oleifera*, biofuel, energy sustainability.

Balanco energético da cultura de canola visando à produção de biodiesel

RESUMO: *O objetivo do trabalho foi estimar o balanço energético (razão output/input) da cultura da canola, nas condições brasileiras, para a produção de biodiesel. A energia fóssil dispendida na produção de 600kg de óleo por hectare foi de 7.146.537kcal. O rendimento energético estimado por hectare foi de 9.930.000kcal, a partir da produtividade de 1.500kg ha⁻¹ de grãos (40% de óleo e 60% de torta), resultando no valor do balanço energético de 1,39. Os resultados indicam a viabilidade da produção do biocombustível com base na respectiva cultura, mas demonstram também a necessidade de aperfeiçoamento das tecnologias empregadas para que se aumentem os índices dos balanços energético e econômico.*

Palavras-chave: *Brassica napus* L. var. *oleifera*, biocombustível, sustentabilidade energética.

INTRODUCTION

The main global energy matrix is composed of non-renewable fossil carbon sources such as petroleum (35%), coal (23%), and natural gas (21%), and it is highly likely that these sources will become scarce in the coming decades. Moreover, the extensive use of these fuels is potentially damaging to the environment (SOUZA, 2008). The global production of biodiesel has significantly increased in recent years, and there is a growing interest in gradually replacing fossil fuels with biofuels (GARCEZ & VIANNA, 2009).

Brazil has great potential for the production of biofuels, since it has a rich diversity of agricultural

species that can potentially be used for this purpose, and because a labor force and land are readily available. Due to these characteristics, Brazil is in a good position to be a powerhouse in the international market of the renewable fuel production agribusiness. Despite the optimism involved, the amount of energy invested in a production system has often been greater than the return obtained in the form of the energy value of products, which leads to a negative balance and thereby compromises the sustainability of the system (PIMENTEL & PATZEK, 2005). Therefore, several studies have been conducted with the aim of assessing the efficiency of new renewable energy, in order to determine the economic and energetic viability of biofuel production. Energy balance,

defined by CAMPOS & CAMPOS (2004) as the ratio between the energy produced per unit of area (production/ha) and the energy consumed per unit of area (input/ha), has been used as an instrument in these studies.

Although the main crop used to obtain biodiesel in Brazil is soybean (KOHLHEPP, 2010), other crops such as canola are potentially suited for this purpose in the central, southeast, and southern regions of Brazil. Rapeseed/canola (*Brassica napus* L. var. *oleifera*) is an important feedstock for biodiesel production due to the high oil content in the grains (40% to 46%). In Brazil, canola is an excellent crop option, for both production of oils for human consumption and agroenergy purposes, and is mainly exported to Europe and other countries where conditions in winter are severe (TOMM et al., 2009). Although there are good prospects for the use of canola in biodiesel production in Brazil, studies that indicate the viability of canola for this purpose are scarce in the country.

The aim of the present study was to estimate the energy balance of the rapeseed/canola crop for biodiesel production under Brazilian conditions within its chain production. This estimate was derived from the relationship between the energy requirements and input costs for fuel production (inputs) and the energy associated with the yields of its combustion added to the energy potential of the oil cake obtained as an industrial by-product (outputs), which are important indicators of the energy viability of biodiesel production.

MATERIALS AND METHODS

To calculate the energy balance of the canola (*Brassica napus* L. var. *oleifera*) crop, the different activities involved in the production system were divided into an agricultural and an industrial phase.

The agricultural phase was conducted via a field experiment in which the invested mechanized and manual operations were estimated, as well as all the inputs used, according to the technical recommendations for the crop's management (BATCHELOR et al., 1995; PIMENTEL & PATZEK, 2005; TOMM, 2006; TOMM et al., 2009; LIMA, 2009; GARAVAND et al., 2010). The experiment was conducted in a rural property in the municipality of Itumirim-MG (latitude 21°16'35"S, longitude 44°49'34"W) between 2009 and 2010. The experimental design was in randomized blocks, with five plots of 0.2ha each and five replicates, where the set of plants from the central part of each plot was considered as one treatment, and where a production

test of the crop was conducted under local conditions and using local technologies. A mean of 4kg of canola seeds were sown per hectare. Crop fertilization was performed by applying 200kg of N-P-K (4-30-16) formulation, 100kg of ammonium sulfate, and 71kg of urea (TOMM, 2006; TOMM et al., 2009). All the remaining inputs, technologies and work force that were used are described in tables 1 and 2. Mean productivities per area were obtained, from which mean grain yields per hectare of crop were subsequently inferred.

The industrial phase included the operations of oil extraction, refining, and transesterification to obtain biodiesel, and the estimated yields were obtained in the form of oil and of oil cake, to which the total costs of the energy invested in the production process were then related. For oil extraction, grain samples were subjected to cold pressing in an expeller press. Refining and transesterification operations were performed subsequently, according to the method of BATCHELOR et al. (1995).

To estimate the energy balance, all the inputs invested in the process of grain and oil production were considered: mechanized operations, labor force, inputs, and the industrial phase (Table 1). The outputs were relative to the amount of energy in the final products. Energy efficiency was calculated using the ratio between the produced energy (outputs) and the consumed energy (inputs).

Expenditures in the mechanized operations were estimated considering direct energy (fuels, oils, and greases) and indirect energy (tractors and implements) invested in the production process of this crop. Energy inputs and outputs were subsequently related to their corresponding energy balance (Table 1), and the total energy consumed in each process and the total energy yield from the produced oil and oil cake were thus obtained. After calculating the total energy consumed and produced, the energy balance for the canola crop was estimated.

To complement the data on the potential of canola crops in the region, the production costs during the agricultural phase and the grain yields per hectare were estimated, according to the corresponding monetary relative to the market price in the region of Lavras-MG for the year 2012 (Table 2).

RESULTS AND DISCUSSION

The total fossil energy invested in the production of 600kg of canola oil per hectare was estimated at 7,146,537kcal. This yield in oil was obtained from the data in table 1, considering that the mean grain yield for the canola crop was 1,500kg ha⁻¹ (40% oil and 60% oil cake).

The estimated energy balance for biodiesel production from canola was 1.39. This means that for each 1kcal of energy invested in the production system, 1.39kcal of energy was produced from the crop. This energy yield was estimated from the total energy produced by the crop, specifically 9,930,000kcal ha⁻¹ (Table 1), considering the values of energy contained in the produced oil and oil cake.

The agricultural phase represented approximately 63% of all the invested energy for biodiesel production, with the inputs corresponding to the major part of invested energy (approximately 25%). Nitrogen alone represented 13.65% of the consumed energy (Table 1). The remaining energy invested in the agricultural phase resulted from the

labor force, diesel fuel and mechanized operations, accounting for 22.97, 7.50, and 7.23% of all the energy invested in the production process, respectively. The industrial phase represented approximately 37% of the total energy invested in the process of oil production from canola and included the extraction, transesterification, and refining operations.

The positive energy balance obtained indicates the viability of biodiesel production from canola under the given production conditions. However, the viability of biofuel production becomes debatable when the energy balance ratios obtained in the present study; although, they represent significant yields - are compared with the energy balance ratios obtained in other studies with this crop and with other

Table 1 - Energy balance for biodiesel production from canola in the region of Itumirim, Minas Gerais, Brazil.

Agricultural phase	Consumed	kcal	Total kcal	%
Plowing ¹	1ha	40959 ha ⁻¹	40959	0.57
Harrowing ¹	1ha	9088.09 ha ⁻¹	9088.09	0.13
Insect spraying ²	0.6h m ⁻¹	191076.72 h ⁻¹	114646	1.60
Herbic spraying ²	0.6h m ⁻¹	191076.72 hm ⁻¹	114646	1.60
Application of feart ²	0.12h m ⁻¹	226906.61 hm ⁻¹	27228.79	0.38
Sowing ¹	1ha	22217 ha ⁻¹	22217	0.31
Harvest ³	1h m ⁻¹	187131h m ⁻¹	187131	2.62
Transportation ⁴	0.5h m ⁻¹	1321.4h m ⁻¹	661	0.01
Total	-	-	516577.09	7.23
-----Labor force-----				
Total	144L	11400 L ⁻¹	1641600	22.97
-----Inputs-----				
Nitrogen ⁵	60.95kg	16000kg ⁻¹	975200	13.65
Phosphorous	60kg	4154kg ⁻¹	249240	3.49
Potassium	32kg	3260kg ⁻¹	104320	1.46
Glyphosate herbic ⁵	1kg	100000kg ⁻¹	100000	1.40
Insecticide ⁵ Methaminadophos ⁵	2.95kg	100000kg ⁻¹	295000	4.13
Seeds ⁶	4kg	21700kg ⁻¹	86800	1.21
Total	-	-	1810560	25.33
-----Diesel oil/liters-----				
Total	47	11400 L ⁻¹	535800	7.50
Total Agrícola Phase	-	-	4504537	63.03
Industrial Phase ⁷	Consumed	kcal	Total kcal	%
Extraction	1	555000 ha ⁻¹	555000	7.77
Refining	1	581000 ha ⁻¹	581000	8.13
Transesterification	1	1506000 ha ⁻¹	1506000	21.07
Total	-	-	2642000	36.97
Total Inputs	-	-	7146537	100
-----Yields-----				
Oil	600kg	8900	5340000	-
Oil cake	900kg	5100	4590000	-
Energy produced	-	-	9930000	-
Energy Balance	-	-	1.39	-

* Values obtained according to the energy ratios of the following studies: ¹SIQUEIRA et al., 1999, ²SOARES et al., 2007, ³MELLO, 1989, ⁴FREITAS et al., 2006, ⁵PIMENTEL & PATZEK, 2005, ⁶GARAVAND et al., 2010, ⁷BATCHELOR et al., 1995.

crops such as soybean, which is the main feedstock for biodiesel production in Brazil. UNAKITAN (2010) obtained an energy balance of 4.68 from a mean yield of 3,099.89kg ha⁻¹ of canola grains, considering only the embedded energy value per kg of produced grains. For the soybean crop, GAZZONI et al. (2005) obtained an energy balance of 4.75 for a yield of 4,000kg ha⁻¹, considering the yields in energy contained in the produced oil and oil cake.

Grain yields obtained by canola producers in Paraguay were greater than 2,044kg ha⁻¹ and the genetic materials used have the potential to produce up to 4,500kg of grains ha⁻¹ (TOMM, 2006). The production of 1,500kg ha⁻¹ that was obtained in the present study is generally considered medium-low. Increasing production would be a good alternative to increase the energy and the systems' yields.

Considering the technologies used, the greatest monetary costs of the agricultural phase (canola grain production) were related to the inputs, which represented 50.67% of the total production costs (Table 2). Mechanized operations and labor force represented approximately 36.45% and 12.88%,

respectively, of the total costs of production. The total monetary cost of the agricultural phase of the production of one hectare of canola was approximately R\$ 1,048.13 (Table 2).

Conversely, the monetary yield for the crop, considering the grains produced and their commercial value in the regional market in 2012, was approximately R\$ 2,025.00. The positive return in terms of economic balance of the agricultural phase of canola production indicated that this crop has economic potential for grain production in the region. However, because the cost analysis was based on the conditions required for the present study, further studies are needed to investigate the economic viability of canola grain production for a variety of purposes, including biodiesel production, in a wide range of production conditions.

The results indicated that the main production bottle necks were associated with the agricultural phase of production and that, in this phase, the inputs corresponded both with the highest energy expenditures and with the highest monetary costs. Therefore, investments should be made to improve the

Table 2 - Economic balance of the agricultural phase for the production of 1,500 kg/ha of canola grains in the region of Itumirim/Lavras, Minas Gerais, Brazil, 2012.

	Quantity	Value/Unit	Total	Percentage
Agricultural phase	Hour/machine	R\$	R\$	%
Mechanization				
Plowing	1	50,00	50,00	4.77
Harrowing	2	50,00	100,00	9.54
Sowing	1	50,00	50,00	4.77
Insecticides	0.6	50,00	30,00	2.86
Herbicides	0.6	50,00	30,00	2.86
Fertilizers	0.12	50,00	6,00	0.57
Harvest	1	100,00	100,00	9.54
Transportation	0.5	32,00	16,00	1.53
Total	-	-	382,00	36.45
Labor force	Hour/man			
Total	36	3.75	135.00	12.88
Inputs	200kg	1.19	238.00	22.71
4-30-16	100kg	0.71	71.00	6.77
Ammon Sulfate	71kg	1.03	73.13	6.98
Urea	2L ha ⁻¹	7.00	14.00	1.34
Glyphosate Methamidophos	2.5L ha ⁻¹	14.00	35.00	3.34
Seeds	4kg	1.50	6.00	0.57
Diesel	47L	2.00	94.00	8.97
Total	-	-	531.13	50.67
Total cost			1048.13	100
Yields (kg grains)	1500	1.35	2025	-
Economic balance	-	-	1.93	-

technologies used and to familiarize farmers in various regions of Brazil with the cultivation of canola. In addition, it is clear that there is a need for investment in genetic improvement programs to obtain cultivars that are more adapted to our plantation regions. These improvements would increase mean yields as well as the energy and economic potential of this crop in Brazil.

CONCLUSION

Results indicated the energy viability of biodiesel production from canola.

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