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Energy and budget balances for sweet potato-based ethanol production

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Abstract – The objective of this work was to assess the viability of sweet potato (*Ipomoea batatas*) for ethanol production, as well as to estimate the energy and budget balances for the crop. Data from the agricultural and industrial production phases were evaluated. Those from the agricultural phase were estimated from a field experiment and used for comparison of sweet potato genotypes. Those from the industrial phase were estimated based on the literature on the fossil fuel energy and electricity consumed in the ethanol production process. With average yields of 35 Mg ha^{-1} roots and 12 Mg ha^{-1} dry stems, the output/input ratios were 6.64 and 1.93 for the energy and budget balances, respectively. For yields of 50 and 80 Mg ha^{-1} roots (17 and 27 Mg ha^{-1} dry stems, respectively), the indexes for energy balance were 7.16 and 7.68, respectively, and those for energy budget were 2.76 and 4.42. The obtained results confirm the great aptitude of the sweet potato crop for biofuel production.

Index terms: *Ipomoea batatas*, alternative energy sources, biofuel, corn, energetic sustainability, sugarcane.

Balanços energético e econômico para produção de etanol a partir de batata-doce

Resumo – O objetivo deste trabalho foi avaliar a viabilidade da batata-doce (*Ipomoea batatas*) para produção de etanol, bem como estimar os balanços energético e econômico para a cultura. Foram avaliados dados das fases agrícola e industrial de produção. Os da fase agrícola foram estimados a partir de experimento conduzido em campo e usados para comparação de genótipos de batata-doce. Os da fase industrial foram estimados com base na literatura sobre as energias fóssil e elétrica consumidas no processo de produção de etanol. Com a produção média de 35 Mg ha^{-1} de raízes e 12 Mg ha^{-1} de ramas secas, as razões entre rendimentos/investimentos foram de 6,64 e 1,93 para os balanços energético e econômico, respectivamente. Para as produtividades de 50 e 80 Mg ha^{-1} de raízes (17 e 27 Mg ha^{-1} de matéria seca de ramas, respectivamente), os índices de balanço energético foram 7,16 e 7,68, respectivamente, e os de balanço econômico, 2,76 e de 4,42. Os resultados obtidos confirmam a grande aptidão da cultura de batata-doce para produção de biocombustível.

Termos para indexação: *Ipomoea batatas*, fontes alternativas de energia, biocombustível, milho, sustentabilidade energética, cana-de-açúcar.

Introduction

The importance of renewable energy resources has been increasing with the rising demand for energy (Stephenson et al., 2010; Kazem,

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2011) and the expectation that biofuels, such as ethanol, biodiesel, and those derived from solid biomass materials (for example, wood or vegetable charcoal), will at least partially replace fossil fuels (Tian, 2018).

Brazil has a great potential for the production of ethanol biofuel from sugarcane (*Saccharum officinarum* L.) or from alternative sources, such as sweet potato (*Ipomoea batatas* L.), to be consolidated through research (Cantos-Lopes et al., 2018; Costa et al., 2018; Silva et al., 2018).

Sweet potato is an easy-to-grow vegetable, which is well adapted to climatic conditions and relatively tolerant to dry periods, cultivated mainly by family farmers. The plant has several uses for all of its parts: the roots, for human consumption; and the leaves and stems, as animal feed (Massaroto, 2008; Motsa et al., 2015; Lim, 2016).

In Brazil, sweet potato root yield is usually low, especially due to the use of obsolete materials and propagules contaminated with pathogens, besides the lack of widespread technology (Miranda, 2015). In the country, the average root yield is 12 Mg ha^{-1} (Produção agrícola municipal, 2010); 30 years ago, yields from 11 to 13 Mg ha^{-1} were already considered low and one of the main factors limiting the recommendation of sweet potato as an alternative source of ethanol (Oliveira et al., 2017). However, there are reports of root yields of up to 98 Mg ha^{-1} (Gonçalves Neto et al., 2011), indicating that there is technology available to reach very high yields.

It has been shown that, in some cases and for some cultures, the energy input of a production system is frequently greater than its energy intake (Pimentel & Patzek, 2005), which compromises the sustainability of the system. Therefore, several studies have been carried out to evaluate the efficiency of new potential sources of renewable energy, particularly aiming to check their economic and energetic viability for biofuel production (Maino et al., 2019; Silva et al., 2017a, 2017b). For this, the net energy balance is commonly used, which is defined as the relationship between the energy produced per unit area and the energy consumed by this same unit area. Moreover, data on consumed energy and on energy efficiency are considered important to diagnose the sustainability of agricultural productive systems. However, further studies are still necessary for data collection and information on energy coefficients more specific for different cultures (Chechetto et al., 2010), mainly sweet potato.

The objective of this work was to assess the viability of sweet potato for ethanol production, as well as to estimate the energy and budget balances for the crop.

Materials and Methods

The activities involved in the production of ethanol from sweet potato were divided into two phases: agricultural and industrial. In the agricultural phase, 79 sweet potato genotypes were compared using data from a field experiment carried out at the vegetable experimental station of HortiAgro Sementes S.A., located at Palmital farm, in the municipality of Ijaci, in the state of Minas Gerais, Brazil (21º14'16"S, 45º08'00"W, at an average altitude of 918 m).

The material was first sown in expanded polystyrene trays – with 72 cells, each filled with approximately 120 mL of the commercial substrate Plantmax –, which were kept in a greenhouse. Stems with 20 cm of length and three to four internodal buds were used. Thirty days after planting, the seedlings were taken to the field and transplanted to the previously raised 40-cm ridges.

The sweet potato crop was sown in February 2012, under irrigated conditions, considering that the average rainfall from March to October, in Lavras, a nearby municipality, in the same state, is 476 mm (Dantas et al., 2007) and that the average water use in the crop cycle is 6,176 m^3 ha^{-1} (Lima et al., 1999). After plowing, 1.000 kg ha^{-1} of the N-P_2O_5-K_2O (4-14-8) fertilizer was broadcast over the experimental area, which was harrowed twice.

The plots consisted of grooves with 12 plants each, with 0.30 m between plants and 1.00 m between rows, totalizing a final population of 33,333 plants per hectare. Harvesting was performed seven months after planting. Roots were then weighed to obtain total yield, expressed in megagrams per hectare.

In the agricultural phase, the investments were on energy expenditures for mechanical and manual operations and on the used inputs, according to the technical recommendations for the crop (Lima et al., 1999; Gliessman, 2000; Freitas et al., 2006). In the industrial phase, the investments were on fossil fuel energy and the energy consumed in the production of 1.0 L ethanol (Nguyen et al., 2007).

The industrial phase consisted of the stages for the production of ethanol from starchy sources (Nguyen et al., 2007), i.e.: heating, to dilute and gelatinize sweet potato starch; enzymatic hydrolysis, in which the gelatinized starch is transformed into fermentable sugars (di- and monosaccharides); and fermentation, in which di- and monosaccharides are subjected to a fermentation process by yeast, which produces alcohol (ethanol) and CO_2. The fermentation process is divided into three stages: substrate preparation, fermentation, and distillation. The yeast inoculated in the substrate is maintained under adequate conditions for its establishment and posterior production of hydrated alcohol (ethanol). Through fermentation, fermented must (wine), composed of approximately 8.5% (volume) alcohol, and the other components are obtained. The alcohol in the wine is recovered by distillation, when the mixture is heated until the boiling point and vapors are cooled for condensation. In this process, an increase is expected in the concentration of the most volatile component (alcohol) in the vapor and of the less volatile one (fermented broth) in the liquid. When wine is distilled, it is possible to reach a content close to 96% ethanol (hydrated alcohol). At the end of the process, from each megagram per hectare of processed sweet potato, besides ethanol, 150 kg of a residue rich in protein is obtained, which can be directly used for animal feed (Silveira et al., 2008).

Consumed energy was estimated from the values of equivalent energy embodied in the several production components (Table 1). Energy efficiency was determined from the amount of energy in ethanol, in the solid residue obtained in the industrial process, and in stem dry matter. Specifically for stem dry matter and industrial solid residue, energy efficiency was calculated from the total digestible nutrient (TDN) content, using data on acid detergent fiber (ADF) content from the stem dry matter (Monteiro et al., 2007) and solid residue (Rodrigues et al., 2012), through the equation proposed by Undersander et al. (1993): TDN = 87.84 - (0.7X%ADF). Considering that each kilogram of mix silage corresponds to 0.0184 GJ energy (Roston & Andrade, 1992), it was possible to obtain the energy efficiency indexes for each scenario. Energy balance was then calculated using the relationship between produced (efficiency) and consumed (investments) energy.

Table 1. Embodied energy (GJ per unit) in the production of ethanol from sweet potato (*Ipomoea batatas*) roots.

Investment	Unit	Embodied energy	Reference
		Agricultural phase	
Mechanized operations[(1)]			
Plowing	Hour machine	0.1715	Siqueira et al. (1999)
Harrowing for leveling	Hour machine	0.0190	Siqueira et al. (1999)
Fertilization and opening grooves	Hour machine	0.0199	Freitas et al. (2006) and Souza et al. (2008)
Irrigation	kW h^{-1}	0.0036	Lima et al. (1999)
Internal transportation	Hour machine	0.0055	Freitas et al. (2006)
Labor[(2)]			
Opening grooves	Day man	0.0063	Souza et al. (2008) and Gliessman (2000)
Preparing and selecting seedlings	Day man	0.0100	Souza et al. (2008) and Gliessman (2000)
Planting by hand	Day man	0.0063	Souza et al. (2008) and Gliessman (2000)
Weeding by hand	Day man	0.0167	Souza et al. (2008) and Gliessman (2000)
Harvesting	Day man	0.0167	Souza et al. (2008) and Gliessman (2000)
Inputs			
Nitrogen	kg	0.0670	Pimentel & Patzek (2005)
Phosphorus	kg	0.0174	Pimentel & Patzek (2005)
Potassium	kg	0.0136	Pimentel & Patzek (2005)
Diesel	L	0.0477	Pimentel & Patzek (2005)
		Industrial phase	
Electricity and fuel fossil energy when processing 1.0 L ethanol from starch	GJ L^{-1}	0.00669	Nguyen et al. (2007)
		Yield	
Ethanol	L	0.0215[(3)]	Álvares Junior & Linke (2001)

[(1)]The costs with mechanized operations were estimated from the directly (fuel, labor, fertilizer, and agrochemicals) and indirectly (tractor and other machinery) embodied energy in the production system. [(2)]The labor of one man per day is equivalent to 8 hours of manual work. [(3)]By transforming liters into kilograms, this value represents a greater calorific power.

Energy balances for the production scenarios with 35, 50, and 80 Mg ha^{-1} roots and 12, 17, and 27 Mg ha^{-1} stem dry matter, respectively, were calculated based on the average yields for the roots of the different clones evaluated in this experiment and on the average yields for stem dry matter found by Gonçalves Neto et al. (2011) for clones with root yields greater than 25 Mg ha^{-1}. It was considered that each ton of sweet potato produces approximately 160 L ethanol and 150 kg dry residue (Silveira, 2008). A great number of clones showed a yield of 35 Mg ha^{-1} roots, indicating that this value could be reached short term in Brazil, if all technical recommendations for the crop are adopted. It should be highlighted that only clones with a good aptitude for root biomass production reached 50 Mg ha^{-1} yield, and only the best ones (elite clones) reached 80 Mg ha^{-1}. The average sweet potato yield in Brazil, of 12 Mg ha^{-1}, was not considered for comparisons since it reflects a rudimentary technology level, which is not recommended for the crop by research institutions.

The production cost per hectare, in the agricultural phase, was estimated based on the monetary values of the second semester of 2011, in the region of Lavras, in the state of Minas Gerais, Brazil (Table 2). The total net income was obtained from the three average yields considered, taking into account that the price of a ton of sweet potato was two-fold that payed to the producer for a ton of sugarcane and that the average yield in liters of the ethanol produced by processing sweet potato roots is twice that of sugarcane (Silveira, 2008). Budget balance was calculated by the relationship between revenue and expenditures.

Results and Discussion

The results of root and stem production of sweet potatoes obtained experimentally in the region of Lavras, MG, vary greatly according to each clone tested, from 0.7 Mg ha^{-1} to 98 Mg ha^{-1} of fresh roots; while stem dry matter vary from 4.3 Mg ha^{-1} to 65.9 Mg ha^{-1} (Table 3). The obtained data clearly represent the enormous productive potentials of some clones and base the productive simulations for the energy balance calculations in each studied reality.

The total energy embodied in the first production scenario using 35 Mg ha^{-1} roots and 12 Mg ha^{-1} stem dry matter was 49.30 GJ ha^{-1} (Tables 4, 5, and 6). For the second and third scenarios, using 50 Mg ha^{-1} roots and 17 Mg ha^{-1} stem dry matter and 80 Mg ha^{-1} roots and 27 Mg ha^{-1} stem dry matter, respectively, the total energy embodied was 65.36 and 97.47 GJ ha^{-1}.

Considering the yields of the different studied clones, in the first production scenario, 5,600 L ethanol, 3,899 kg TDN in dry residue, and 10,488 kg TDN in stem dry matter were obtained. In the second scenario, the values were 8,000 L ethanol, 5,570 kg TDN in dry residue, and 10,488 kg TDN in stem dry matter, whereas, in the third scenario, they were 12,800 L ethanol, 8,912 kg TDN in dry residue, and 16,780 kg TDN in stem dry matter. Energy efficiency was estimated from the total energy embodied in each scenario: 327.36, 467.65, and 748.25 GJ for the first, second, and third scenarios, respectively.

The agricultural phase represented 24, 18, and 12% of all the energy embodied in the production of 35, 50,

Table 2. Expenditure during the agricultural phase for the production of 1.0 ha sweet potato (*Ipomoea batatas*).

Investment	Unit	Quantity	Cost (R$)	Total (R$)	Percentage
			Agricultural phase		
Mechanized operations					
Plowing	Hour machine	1	50	50	2.02
Harrowing for leveling	Hour machine	2	50	100	4.03
Fertilization and opening grooves	Hour machine	3	90	270	10.89
Irrigation	kW h^{-1}	808	0.18	146	5.89
Internal transportation	Hour machine	0.5	50	25	1.01
Subtotal		-	-	591	23.84
Manual operations	Day man	40	25.00	1,000.00	40.34
Subtotal		40	25.00	1,000.00	40.34
Input					
N-P_2O_5-K_2O (4-14-08) fertilizer	kg	1,000	0.80	800.00	32.27
Diesel	L	40	2.20	88.00	3.55
Subtotal				888.00	35.82
Total		-	-	2,479	100

and 80 Mg ha^{-1} roots, respectively. In every scenario in this phase, inputs corresponded to the greatest amount of the total energy embodied.

The total net investment, in the agricultural phase, was R$ 2,475.48 (Table 2). Most of the expenses were with labor, representing 40% of total costs, followed by inputs, totalizing 36% of these costs. Net incomes were estimated from the value of R$ 0.14 per kilogram of roots, equivalent to two-fold the average price paid to the producer for 1.0 ton of sugarcane. These prices resulted in incomes of R$ 4,788.00, 6,840.00, and 10,944.00 per hectare for 35, 50, and 80 Mg ha^{-1} roots, respectively. The input/out ratios for energy and budget balances were 6.64 and 1.93, respectively, for 35 Mg ha^{-1} roots and 12 Mg ha^{-1} stem dry matter. Although this production is greater than the national

Table 3. Average yields of roots and aerial parts of sweet potato (*Ipomoea batatas*) observed experimentally in the municipality of Lavras, in the state of Minas Gerais (UFLA-2011/2012).

Clones	Root productivity (Fresh matter – Mg ha^{-1})				Dry steam (Mg ha^{-1})
	>50	50> 25	<25	Controls	Dry matter
UFLA07-12[1]	98.0	-	-	-	20.0
UFLA07-43[1]	95.0	-	-	-	20.3
2007HSF001-24	75.5	-	-	-	18.5
2007HSF002-05	70.1	-	-	-	13.6
2007HSF002-19	62.0	-	-	-	9.8
2007HSF010-12	55.6	-	-	-	10.5
CNPH Laranja	-	-	-	52.2	6.8
2007HSF022-19	59.2	-	-	-	15.9
2007HSF004-04	54.2	-	-	-	5.6
2007HSF030-02	52.8	-	-	-	23.0
2007HSF028-16	-	47.8	-	-	11.4
2007HSF027-16	-	42.8	-	-	18.8
2007HSF024-06	-	48.7	-	-	4.6
2007HSF031-04	-	38.6	-	-	29.1
2007HSF024-04	-	45.9	-	-	7.0
2007HSF004-17	-	46.4	-	-	10.6
Brazlandia Roxa	-	-	-	33.5	15.7
2007HSF025-04	-	41.1	-	-	9.0
2007HSF006-16	-	31.5	-	-	23.2
2007HSF002-14	-	40.6	-	-	9.8
2007HSF001-28	-	45.3	-	-	2.9
2007HSF010-33	-	38.1	-	-	18.4
2007HSF022-10	-	44.2	-	-	10.2
2007HSF010-41	-	37.9	-	-	6.1
2007HSF022-05	-	34.9	-	-	22.2
2007HSF014-05	-	30.9	-	-	22.8
Ufla07-49	-	31.5	-	-	13.9
Clones	> 50	50> 25	<25	Controls	Dry matter
2007HSF001-01	-	32.5	-	-	8.5
2007HSF022-09	-	35.9	-	-	13.4
2007HSF005-06	-	30.7	-	-	16.5
2007HSF020-08	-	33.1	-	-	17.9
Ufla07-53	-	32.5	-	-	11.8
2007HSF026-05	-	28.1	-	-	29.6
2007HSF002-04	-	27.8	-	-	13.1
2007HSF011-01	-	30.3	-	-	28.7
2007HSF021-01	-	31.1	-	-	67.9
2007HSF009-06	-	-	23.1	-	7.3
2007HSF001-26	-	27.6	-	-	35.7
2007HSF002-08	-	31.9	-	-	16.4
2007HSF004-06	-	26.3	-	-	24.6
2007HSF027-10	-	-	20.6	-	11.0
Itajubá-2012	-	26.4	-	-	43.8
2007HSF010-35	-	28.2	-	-	14.5
2007HSF010-47	-	-	21.7	-	13.4
2007HSF022-12	-	26.0	-	-	29.1
2007HSF010-06	-	-	22.6	-	6.3
2007HSF002-11	-	-	22.5	-	14.6
Ufla07-15	-	-	21.8	-	33.2
2007HSF020-07	-	25.6	-	-	7.9
2007HSF027-05	-	-	23.1	-	27.2
2007HSF028-05	-	25.7	-	-	3.0
2007HSF012-02	-	-	23.6	-	11.2
2007HSF020-12	-	-	22.5	-	28.1
2007HSF002-02	-	-	20.6	-	21.6
2007HSF010-23	-	-	20.0	-	13.2
2007HSF005-01	-	28.5	-	-	9.7
2007HSF010-31	-	26.1	-	-	13.4
2007HSF010-17	-	-	19.5	-	10.5
2007HSF029-01	-	-	21.4	-	14.6
2007HSF028-08	-	-	19.4	-	6.2
2007HSF027-07	-	-	17.2	-	20.7
2007HSF001-37	-	-	19.3	-	17.1
2007HSF011-05	-	-	19.3	-	13.7
2007HSF011-06	-	-	16.0	-	17.4
2007HSF027-12	-	-	17.9	-	19.7
2007HSF022-04	-	-	14.0	-	15.5
2007HSF001-21	-	-	13.0	-	36.2
2007HSF001-17	-	-	12.2	-	65.9
Palmas	-	-	-	13.5	11.9
2007HSF023-08	-	-	12.6	-	42.7
2007HSF026-02	-	-	12.5	-	23.8
2007HSF007-26	-	-	12.4	-	29.2
Brazlandia Rosada	-	-	-	8.5	5.8
2007HSF007-21	-	-	9.1	-	9.2
2007HSF006-13	-	-	8.8	-	42.6
2007HSF014-04	-	-	9.0	-	48.2
Álvaro-2012	-	-	12.2	-	4.9
2007HSF005-03	-	-	6.9	-	4.3
2007HSF001-40	-	-	7.4	-	6.6
2007HSF029-02	-	-	7.9	-	9.5
2007HSF010-01	-	-	0.7	-	9.6

(1)Productivities observed by Gonçalves Neto et al., 2011.

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Table 4. Embodied energy (GJ per unit) in the agricultural phase for the production of ethanol from 1.0 ha sweet potato (*Ipomoea batatas*).

Investment	Unit	Quantity	Consumption	Total
Mechanized operations				
Plowing	Hour machine	1	0.1715	0.1715
Harrowing for leveling	Hour machine	2	0.0190	0.0381
Fertilization and opening grooves	kW h^{-1}	3	0.0199	0.0597
Irrigation	Hour machine	808	0.0036	2.9088
Internal transportation	Hour machine	0.5	0.0055	0.0028
Subtotal		-	-	3.1808
Manual operations[(1)]				
Opening grooves	Day man	1	0.0063	0.0063
Preparing and selecting seedlings	Day man	2	0.0100	0.0200
Hand planting	Day man	10	0.0063	0.0630
Hand weeding	Day man	7	0.0167	0.1172
Harvest	Day man	20	0.0167	0.3349
Subtotal		-	-	0.5414
Input				
Nitrogen	kg	40	0.0670	2.6796
Phosphorous	kg	140	0.0174	2.4349
Potassium	kg	80	0.0136	1.0919
Diesel	L	40	0.0477	1.9092
Subtotal		-	-	8.1155
Total for agricultural phase		-	-	11.8377

[(1)]The labor of one man per day is equivalent to 8 hours of manual work.

Table 5. Fossil fuel energy and electricity embodied in the industrial phase for the production of 1.0 L ethanol from sweet potato (*Ipomoea batatas*), as well as ethanol, residue, and stem yields[(1)].

Parameter	Unit	Quantity	Embodied energy	Total
Investment		30 Mg ha^{-1}		
Fossil fuel energy and electricity	GJ L^{-1}	0.00669	5,600	37
Yield				
Ethanol	GJ L^{-1}	0.0215	5,600	121
Residues	TDN (kg)	0.0184	3,899	72
Stems	TDN (kg)	0.0184	7,341	135
Investment		50 Mg ha^{-1}		
Fossil fuel energy and electricity	GJ L^{-1}	0.00669	8,000	54
Yield				
Ethanol	GJ L^{-1}	0.0215	8,000	172
Residue	TDN (kg)	0.0184	5,570	102
Stems	TDN (kg)	0.0184	10,488	193
Investment		80 Mg ha^{-1}		
Fossil fuel energy and electricity	GJ L^{-1}	0.00669	12,800	86
Yield				
Ethanol	GJ L^{-1}	0.0215	12,800	276
Residue	TDN (kg)	0.0184	8,912	164
Stems	TDN (kg)	0.0184	16,780	309

[(1)]TDN, total digstible nutrientes.

average, it can be easily reached by following the recommendations for the crop (Miranda, 2015), even when clones apt for ethanol production are not used.

The use of clones with an average production of 50 Mg ha^{-1} roots and 17 Mg ha^{-1} stem dry matter resulted in energy and budget balance indexes of 7.16 and 2.76, respectively. For the clones with an average production of 80 Mg ha^{-1} roots and 27 Mg ha^{-1} stem dry matter, these indexes were 7.68 and 4.42, respectively. This increase in the value of the indexes can be attributed to the fact that different yields were reached under the same cropping conditions, with varying genetic material.

If the net income including the aerial parts of the plant had not been taken into account, then the energy balances would be 3.90 for 35 Mg ha^{-1} roots, 4.20 for 50 Mg ha^{-1} roots, and 4.51 for 80 Mg ha^{-1} roots.

Brazil and the United States are worldwide leaders in ethanol production, using sugarcane and corn (*Zea mays* L.), respectively, as their main raw material. In Brazil, the energy balance indexes for the production of ethanol from sugarcane vary. Macedo et al. (2008), for example, found an average of 8.3 for 82 Mg ha^{-1} stalks in the 2002 crop season, based on the energy efficiency of the produced ethanol and of the stalk biomass used as a source for combustion furnaces. Salla et al. (2009) reported a value of 1.1 for 85 Mg ha^{-1}, considering only the efficiency of the produced ethanol. Regarding the production of ethanol from corn, in Brazil, the energy index is 1.19 for 6 Mg ha^{-1}, also considering only the energy efficiency of the produced ethanol (Salla & Cabello, 2010).

The discussed results are indicative that the energy balance of sweet potato – considering its average production and the energy efficiency of the aerial part of the plant –, is similar or greater to that of sugarcane for ethanol production, according to Macedo et al. (2008) and Salla et al. (2009), respectively; in all scenarios, the energy balances for sweet potato, even when the biomass of the aerial part of the plant was not taken into account, are much greater than those obtained by Salla & Cabello (2010) for corn.

Although highly favorable for sweet potato, the calculated energy balances did not take into consideration the duration of the crop cycle. The sugarcane crop cycle is medium length, with cuts every 12 months or more, whereas the sweet potato cycle is of 6 months or a bit longer, evidencing its competitiveness for energy production.

In Brazil, sugarcane counts with consolidated and constantly evolving technology. For sweet potato, however, there is still a long ways to go to reach a comparable technology level. Although the currently available technology allows sweet potato to be competitive energy wise (Miranda, 2015; Saranya et al., 2018), to increase the crop's efficiency, further studies are necessary, particularly related to fertilization, irrigation, genetic breeding, and sowing and harvesting mechanization. Despite this, the production of ethanol biofuel from sweet potato offers the following perspectives for the alcohol sector: an alternative to alcohol production in regions where the sugarcane crop is not recommended; intercrop of early sweet potato clones during the initial development of the sugarcane crop; use of sweet potato as an off-season crop, in crop rotation, when the sugarcane crop is being renewed; and integration of ethanol plant-crop-agriculture by using residues from the distillation process and the biomass of the aerial part of the plant as protein sources for animal feed.

Table 6. Energy and budget balances for the yields of 35, 50, and 80 Mg ha^{-1} roots of sweet potato (*Ipomoea batatas*).

Roots yield	Total energy (GJ)	Percentage (GJ)	Values (R$)
	Energy embodied in the agricultural phase		
35 Mg ha^{-1}	11.84	24.01	2,475
50 Mg ha^{-1}	11.84	18.11	2,475
80 Mg ha^{-1}	11.84	12.14	2,475
	Energy embodied in the industrial phase		
35 Mg ha^{-1}	37.46	76	-
50 Mg ha^{-1}	53.52	82	-
80 Mg ha^{-1}	85.63	88	-
	Total embodied energy		
35 Mg ha^{-1}	49.30	100	2,475
50 Mg ha^{-1}	65.36	100	2,475
80 Mg ha^{-1}	97.47	100	2,475
	Yield		
35 Mg ha^{-1}	327.36	-	4,788
50 Mg ha^{-1}	467.65	-	6,840
80 Mg ha^{-1}	748.25	-	10,944
	Balance		
35 Mg ha^{-1}	6.64	-	1.93
50 Mg ha^{-1}	7.16	-	2.76
80 Mg ha^{-1}	7.68	-	4.42

Conclusions

1. The technologies currently available for the sweet potato (*Ipomoea batatas*) crop allow obtaining

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yields between 50 and 80 Mg ha^{-1} roots, using selected genotypes.

2. With yields from 50 to 80 Mg ha^{-1} roots and 17 to 27 Mg ha^{-1} stem dry matter, respectively, the energy balances of sweet potato are similar to those presented in the literature for sugarcane (*Saccharum officinarum*), but greater than those for corn (*Zea mays*).

3. The sweet potato crop has great aptitude for biofuel production.

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