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ENERGY BALANCE OF IRRIGATED AND RAINFED SORGHUM PRODUCTION

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ABSTRACT: The objective of this study was to evaluate the yield and energy balance of four sorghum genotypes in irrigated and rainfed crops. The experiment was conducted in an irrigation and drainage unit at the Federal University of Grande Dourados (UFGD), in Dourados, Mato Grosso do Sul state (Brazil). The experimental design was a randomized complete block design with split plots (with and without irrigation), testing four genotypes (BRS 506, CV 007, CV 147, and EJ 7281) with four replicates (32 plots). Irrigation provided yield increase in all four genotypes. The respective yield increases were 85.89%, 71.82%, 64.28%, and 63.36% for genotypes EJ 7281, BRS 506, CV 147, and CV 007. The energy efficiency (produced/ used ratio) was on average 3.5 under irrigation, and 2.8 for rainfed crops. These results indicate the lack of competition between sorghum and sugarcane, being the first an alternative for off-season. Irrigation increased productivity, leading to an increase in yield and, consequently, in the amount of extracted energy. Yield gains in response to irrigation were more pronounced for genotype EJ 7281. There was a positive impact of irrigation on the energy balance of the four genotypes, increasing energy efficiency.

KEY WORDS: irrigation, productivity, off-season, ethanol.

INTRODUCTION

Biofuels (bioethanol and biodiesel) are produced from renewable energy sources and have been gaining increasing importance due to rising fossil fuel prices, depletion of oil reserves, and concerns about the greenhouse effect (Moreira, 2010). Thus, several countries have given priority to policies favoring biofuel production and use, with ethanol being the most widely used product. In Brazil, this incentive comes from most cars containing bi-fuel engines, which allow the use of ethanol and/or gasoline.

Currently, most of the ethanol produced in Brazil is extracted from sugarcane (Kohlhepp, 2010; Azevedo et al., 2012). The country is the world's largest producer and has great technical and scientific knowledge within this activity. However, there are other renewable raw materials for biofuel production, such as sugar beet, sugar sorghum, corn, wheat, manioc, sweet potato (amylaceous materials), among others (Cunha & Severo Filho, 2010). These other raw materials can be grown during the sugarcane off-season to use the idle industrial park during this period.

This period is characterized by the occurrence of a marked water deficit in the main sugarcane areas of the country. Therefore, the crops to be cultivated at this time must have a certain tolerance to water and temperature stress. Sweet sorghum (*Sorghum bicolor* L. Moench) is a species adapted to extreme environments of abiotic stresses, especially air temperature and soil moisture (Purcino, 2011). In addition, it is easy to extract sugar from sorghum for fermentation, as with sugarcane (Almeida & Fávaro, 2011; Munyinda et al., 2012), and therefore, the same facilities can be used for the extraction of the broth (Durães, 2011). Therefore, sorghum is one of the most interesting cultivation options in the sugarcane off-season.

Several advantages make sorghum a promising crop, one of the adequate parameters to define its technical viability is energy balance. It can be determined by subtracting the produced energy

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from all expenditures during crop implantation, consisting of an important technological choice and decision-making (Assenheimer et al., 2009). In modern agricultural production, characterized by a high consumption of fossil energy and natural resources, high productivity needs to be reached for a favorable energy balance.

Although sorghum adapts to extreme environments, the adoption of modern production techniques is necessary to confer high productivity and profitability. Thus, irrigation is among the technologies contributing the most to yield increase (Saturnino et al., 2010); however, it also increases the energy input (consumption) in the agricultural system. The response to irrigation varies according to the genotype cultivated. Therefore, choosing genotypes with high yield capacity is essential.

Thus, the objective of this study was to evaluate the impact of supplementary irrigation on the yield and energy balance of four sorghum genotypes.

MATERIAL AND METHODS

The experiment was conducted between 11/06/2012 and 03/06/2013 in the experimental area of irrigation and drainage, Federal University of Grande Dourados (UFGD), located in the city of Dourado/MS, coordinates 22° 11’ 53,9” S of latitude, 54° 56’ 18,9” W of longitude, and average altitude of 452 m. According to Köppen’s classification, local climate is a Cwa type, which stands for humid mesothermal with rainy summer. The soil of the experimental area is classified as Dystroferric Red Latosol. Table 1 shows the soil chemical analysis values.

TABLE 1. Soil chemical analysis.

Analysis*	pH ($CaCl_2$)	P	V	$H^+ + Al^{3+}$	Al^{3+}	Ca^{2+}	Mg^{2+}	K^+
		mg dm^{-3}	%	--------------- $cmol_c\ dm^{-3}$ ---------------				
2012/2013	5	11.2	64.5	4.9	0.05	6.59	2.25	0.37

*Layer, 0-20 cm.

The experimental design was a randomized complete block design with split plots, in which the plots were the treatments with and without irrigation, and the subplots were the four genotypes of sugar sorghum, with four replications, totaling 32 plots. Each plot consisted of four rows with 5 m length and spacing of 0.7 m between rows. The two central plot rows were considered for the evaluations. The four sorghum genotypes used were one cultivar of Embrapa (BRS 506), two hybrids of Canavialis (CV 007 and CV 147), and one hybrid of Ceres Sementes do Brasil (EJ 7281).

Correction of soil with limestone was performed according to the recommendations of the present soil analysis, applying 1.6 t ha^{-1}. At planting, an amount of 350 kg ha^{-1} fertilizer (8-20-20) was applied and, as topdressing, 50 kg ha^{-1} urea was broadcast after 30 days. Seeding was done manually, using nine seeds per linear meter at 3 cm depth, keeping a density of 129,000 plants ha^{-1}.

To guarantee an adequate plant stand, during the initial 30 days of the crop cycle additional irrigation was performed using a sprinkler irrigation system in all treatments. Irrigation was suspended in the rainfed treatment after this period. Rainfed plots developed under natural field conditions (Figure 1).

Irrigation control was performed using tensiometers installed at 0.20 m depth and 0.20 m from the planting row. Three tensiometers were installed in the irrigated area, and tension reading was performed 3 times a week on Mondays, Wednesdays, and Fridays. An irrigation depth was applied which corresponded to the amount necessary to restore the soil moisture to field capacity, based on the current moisture (read in the tensiometer) and soil retention curve from Equation 1. The depth applied to the irrigation treatment totaled 499 mm throughout the cycle (Figure 2).

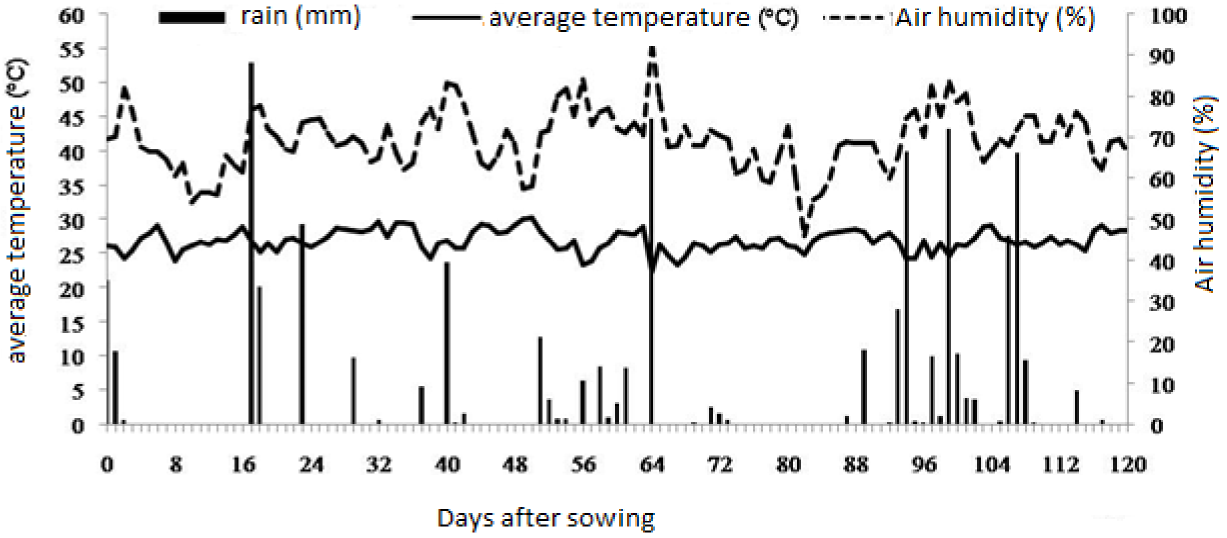

FIGURE 1. Precipitation values (mm), mean temperature (ºC), and relative air humidity (%) from 11/06/2012 to 03/06/2013, in Dourados-MS.

$$\theta a = 0.200 + \left[\frac{(0.589\text{-}0.200)}{[1+ (0.5485\sigma_a)^{19.3221}]^{0.0260}} \right]; (R^2 = 1.00 \text{ and } P < 0{,}01) \qquad (1)$$

In which:

θ_a = current volumetric humidity (cm^3 cm^{-3}),

σ_a = current soil water tension (kPa).

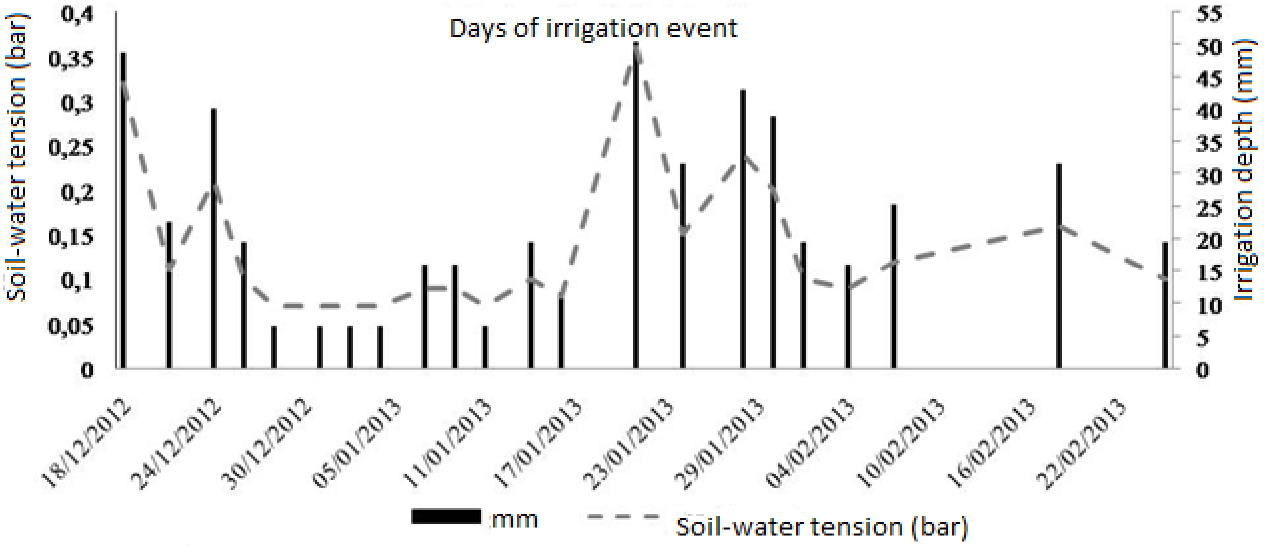

FIGURE 2. Irrigation depths applied according to the mean soil tension.

The harvest was performed 120 days after sowing, and three samples of 15 stems were taken per plot. Samples were weighed for stem yield. The following evaluations were then carried out; fiber (FIB), reducing sugar content in the broth (RS), Brix and TRS (total recoverable sugar), in the laboratory of *Usina Monte Verde* (Bunge) located in the rural area of Ponta Porã (MS). The data were submitted to statistical analysis. Initially, the Kolmogorov-Smirnov test of data normality was performed. When necessary, the data were transformed using the square root method. Afterwards, they were submitted to analysis of variance and the Tukey test at 5% significance.

To perform the energy balance, the results obtained in the experiment were extrapolated to values per hectare, considering all mechanized operations according to data from *Usina Monte Verde*. The agricultural phase was divided into 5 stages: pre-sowing, sowing, management, irrigation, and harvest. In the pre-sowing phase, the preparation activities of the area were liming, plowing, and harrowing. The sowing phase corresponded to conventional seeder operation and fertilization. The management phase consisted of activities such as control activities for weed, pests, fungi, and topdressing (urea). The water depth applied composed the irrigation phase. The methodology by Jordan et al. (2012a), which considers the energy equivalence values, was used to determine the energy used in the sugar sorghum production (Table 2).

TABLE 2. Energy of the inputs used in sugar sorghum cultivation.

Inputs	Unit	Unitary Energy (MJ)
Diesel Oil(1)	L	35.32
Nitrogen(2)	kg	50.28
Phosphorus(2)	kg	12.57
Potassium(2)	kg	6.77
Limestone(2)	kg	1.18
Herbicides(2)	kg	418.62
Insecticides(2)	kg	364.15
Electricity(1)	kWh	3.6
Man-hour(2)	h	2.16

Source: [1]EPE (2014); [2]Jordan et al. (2012a).

The energy depreciation related to the equipment used was performed according to the methodology by Assenheimer et al. (2009) and Jordan et al. (2012a), according to service life, weight, and respective energy coefficients (Table 3).

TABLE 3. Data of the equipment used.

Equipment	Mass (Kg)	Useful life (h)
Limestone distributor(1)	1000(1)	1500(1)
Plough	1000(2)	5000(4)
Harrow	1200(2)	3000(4)
Sprayer	840(2)	1500(5)
Tractor (80 cv)	3000(2)	12000(5)
Seeder	2000(2)	1200(5)
Sugarcane combine (332 cv)	16400(3)	13500(6)

Source: [1]Jordan et al. (2012b); [2]Assenheimer et al. (2009); [3]www.deere.com.br; [4]Checheto et al. (2010); [5]Pacheco (2000); [6]Banchi et al. (2008).

The energy coefficients used according to Assenheimer et al. (2009) were 69.83MJ/kg for self-propulsion equipment (tractor and combine), and 57.20MJ/kg for pulled equipment (plow, harrow, sprayer, etc.). Equations 2 and 3 were used to this end.

$$\mathrm{Eap} = \frac{69.83 \times \mathrm{M}}{\mathrm{Vu}} . \mathrm{H} \tag{2}$$

$$\mathrm{Enp} = \frac{57.20 \times \mathrm{M}}{\mathrm{Vu}} . \mathrm{H} \tag{3}$$

In which:

Eap - energy of automotive equipment ($\mathrm{MJ\ h^{-1}}$);

Enp - energy of non-automotive equipment ($\mathrm{MJ\ h^{-1}}$);

M - equipment mass (kg);

Vu - equipment useful life (h), and

H - hours of equipment use (h).

The average diesel consumption of the tractor was calculated based on the methodology of the Department of Agricultural Engineering, University of Illinois - USA (Kamphorst, 2003), which considers a tractor operating with on average 55% its power, using [eq. (4)] for this calculation. The method suggested by Lyra (2012), of 52.72 L ha^{-1}, was adopted to calculate the average diesel consumption of the combine.

$$Cd = P \times 0.243 \tag{4}$$

In which:

Cd - Diesel consumption (L/ha), and

P - engine power (kW).

For energy balance purposes (calculation of equipment energy depreciation), data from a central pivot, provided by *Valmount Indústria e Comércio Ltda*., were used: central pivot for 115 ha, mass 36000 kg, pumping power 200 hp (specific electric power 1.934 kW ha^{-1}), application intensity of 0.33 mm h^{-1}. A useful life of 20 years (n) and use capacity of 2000 h $year^{-1}$ were adopted (Frizzone et al., 2005).

Energy consumption of the irrigation system (kWh ha^{-1}) was determined by multiplying the specific electric power by the operating time, which was determined based on the water depth applied in each plot, and on the intensity of application. Subsequently, the values were converted to MJ ha^{-1} using the equivalence for electricity (Table 2).

Ethanol productivity was estimated based on TRS values. The maximum possible conversion to ethanol of 1 gram of sugar is 0.511 g, i.e. 100%. It is impossible to convert more than that, because yeast consumes some of the sugar for its activities, including breeding. Therefore, the theoretical maximum, 100%, is 0.511 g/g. Mills work at 91% efficiency on average, which results in 0.465 g ethanol/g of sugar for each gram of sugar. The theoretical maximum conversion (100% efficiency) in sugar fermentation is 0.511 g of ethanol for each gram of sugar. As in practice, this value is lower, the value suggested by Finguerut et al. (2008) was adopted, considering a conversion efficiency of 91% (mean obtained in the mills), resulting in 0.465 grams of ethanol per gram of sugar.

The excess fiber was determined according to LEAL (2007), based on a sugarcane mill with medium efficiency, where the bagasse is burned to supply energy for the ethanol production process, with a surplus of just over 5 %. Only the surplus was considered as recovered energy since the rest is theoretically used in the process.

For the conversion of ethanol and fiber productivity to ethanol, the equivalence of 21.34 MJ L^{-1} was used for ethanol (EPE, 2014), and 18 MJ kg^{-1} (Tolmasquim, 2006) for fiber. The use of energy in the industrial phase was determined according to Tolmasquim (2006), based on values for sugarcane, considering 49.41 MJ per ton processed.

RESULTS AND DISCUSSION

Sugar sorghum is considered a crop resistant to water deficit (Purcino, 2011). However, the treatments cultivated under rainfed conditions, which suffered a total water deficit in the 400 mm cycle, got practically half the yields obtained in the irrigated treatments (64 t ha^{-1}). The average yield was 37.44 t ha^{-1} in the rainfed treatment, which is lower than the national average (EMBRAPA, 2012), and a little higher than the value found by Camacho et al. (2002), which was 35.97 t ha^{-1} for 10 genotypes of sorghum under rainfed conditions. The four genotypes studied presented high responses to irrigation. There was a significant difference between irrigated crops and rainfed ones regarding some yield components such as stem, fiber, and TRS (Table 4).

TABLE 4. ANOVA of the variables evaluated with different sugar sorghum genotypes for rainfed and irrigated crops.

Source of variation	DF	SS	MS	F
Stem yield				
Blocks	3	58.35	19.46	00.7643 ns
Cultivation	1	5778.12	5778.12	226.96 **
Genotypes	3	90.60	30.21	00.5396 ns
Fiber yield (FIB)				
Blocks	3	5.43	1.81	2.75 ns
Cultivation	1	130.89	130.89	198.75**
Genotypes	3	2.37	0.79	0.75 ns
ATR (kg t^{-1})				
Blocks	3	35.00	11.67	0.2017 ns
Cultivation	1	800.00	800.00	13.83*
Genotypes	3	2048.25	682.75	19.55**

DF (degrees of freedom), SS (sum of squares), MS (mean squares), and F (test F)

Productivity increases were higher than 60% for all genotypes, and EJ 7281 showed the highest increase (85.89%), followed by BRS 506 (71.82%). Genotype CV 147 showed the highest productivity in both conditions (irrigated and dry). There was, therefore, a difference between irrigated and rainfed treatments. However, yields among genotypes had no statistical difference within the irrigated and rainfed treatments (Table 5). The average yield of irrigated treatments was 63.98 t ha^{-1}, a value within the productivity range reported by Pereira Filho et al. (2013) for different sorghum cultivars, and higher than the average yield quoted by EMBRAPA (2012), of 50 t ha^{-1}. Fernandes et al. (2014) obtained an average yield of 60.97 t $ha^{-1}$with the BRS 506 genotype in harvest condition.

No statistical difference was observed in fiber content between the genotypes and between the cropping systems (rainfed and irrigation). In terms of fiber yield, following stem yield trend (Table 5), there was an increase for all genotypes with the irrigated treatments. The greatest difference between treatments (irrigated and rainfed) was for genotype EJ 7281 (90.30%), followed by CV 007 (73.74%).

TABLE 5. Stem yield and fiber production (FIB) of different sugar sorghum genotypes.

	Yield (t ha^{-1})		FIB (t ha^{-1})	
Genotypes	Irrigated	Rainfed	Irrigated	Rainfed
BRS 506	63.771 Aa	37.114 Ab	9.687 Aa	5.849 Ab
CV 007	60.771 Aa	37.200 Ab	9.262 Aa	5.331 Ab
CV 147	67.028 Aa	40.800 Ab	9.940 Aa	6.042 Ab
EJ 7281	64.371 Aa	34.628 Ab	9.707 Aa	5.101 Ab

Means followed by the same lowercase letter in the rows, and upper case in the columns, do not differ statistically from each other by the Tukey test at 5% probability. Ns non-significant

The fiber contents obtained for the genotypes (irrigated and rainfed) were within the range described by EMBRAPA (2012), which is from 12 to 20% for sugar sorghum. The yield of total recoverable sugars (TRS) ranged from 103.25 to 122.00 kg t^{-1} for the genotypes submitted to irrigation (Table 6), and genotype BRS 506 presented the highest yield, significantly differing from the others. As for the rainfed condition, the average TRS production ranged from 90.30 to 114.35

kg t^{-1}, and genotype BRS 506 showed the highest yield, with a significant difference in relation to the others.

TABLE 6. Sugar yield (TRS) in the different sugar sorghum genotypes.

	TRS (kg t^{-1})		TRS (t ha^{-1})	
Genotypes	Irrigated	Rainfed	Irrigated	Rainfed
BRS 506	122.00 Aa	114.35 Aa	7.78 Aa	4.23 Ab
CV 007	107.69 Ba	92.61 Bb	6.55 Aa	3.45 Ab
CV 147	103.25 Ba	101.39 Ba	6.92 Aa	4.14 Ab
EJ 7281	105.54 Ba	90.30 Bb	6.82 Aa	3.13 Ab

Means followed by the same lowercase letter in the rows, and upper case in the columns, do not differ statistically from each other by the Tukey test at 5% probability.

There was a significant difference (TRS increase) between the management systems (irrigation and rainfed) only for the genotypes CV 007 (16.28%) and EJ 7281 (16.87%). For sugar yield, also following the trend shown in Table 3, there was an increase from the rainfed condition to the irrigation condition, which varied between 40.23 and 53.97%. The genotype showing the highest average increment was EJ 7281, followed by CV 007.

The TRS values are very close to the values found by Borges et al. (2010), which obtained between 110 and 120 kg t^{-1} for the genotype BRS 506. Uribe & Ticianeli (2014) obtained TRS values between 144 and 118 kg t^{-1} for the same genotype.

Regarding energy expenditure in the agricultural phase (Table 7), in the case of the irrigated treatment, the most representative stage was observed to be irrigation, mainly due to electric energy consumption (Figure 3). On the scale of magnitude came the stages of crop management, pre-sowing, sowing, and harvesting.

TABLE 7. Energy inputs per phase (irrigated and rainfed).

	Agricultural phases (MJ ha^{-1})	
Stages	Irrigated*	Rainfed*
Pre-sowing	4,019.39	4,019.39
Sowing	3,358.32	3,358.32
Crop management	5,171.45	5,171.45
Irrigation	6,792.86	519.67
Harvest	2,037.03	2,037.03
Total	21,379.01	15,105.86

*Values refer to each genotype used (BRS 506, CV 007, CV 147, and EJ 7281).

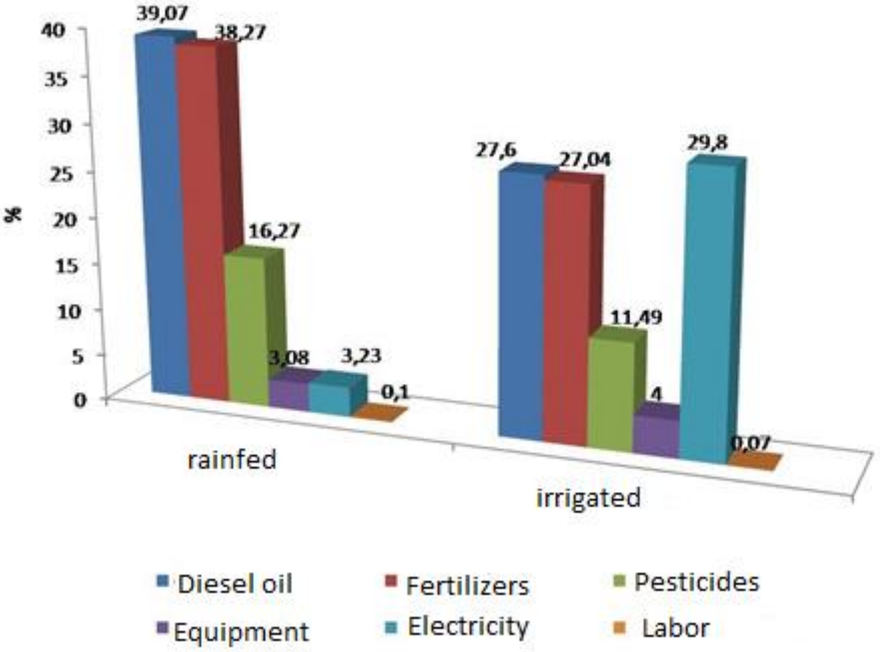

FIGURE 3. Percentage contribution of each type of input in the energy consumption for the production of sugar sorghum - agricultural phase.

The stage requiring the most energy in rainfed treatments (agricultural phase) was crop management, due to the high number of operations (application of herbicide, insecticide, cover fertilization), with great weight from the consumption of diesel oil and the use of fertilizers (Figure 3). Subsequently came the stages of pre-sowing, sowing, harvesting, and initial irrigation applied during the implantation phase of the experiment (first 30 days).

The total energy input used in the irrigated treatment was 41.53% higher than the total energy input used in the rainfed treatment. However, the productivity increase in the area under irrigation during the whole cycle reached 85.89% (Table 4). Fertilizers and diesel oil were the main energy inputs (Figure 3) likewise observed by Checheto et al. (2010) and Jordan et al. (2012a), coming after only electricity, the main input in irrigated areas given the power consumed by the pumping system.

Fiber yield in the irrigated treatment ranged from 9.262 to 9.940 t ha^{-1}, while the ethanol yield estimate ranged from 3760 to 4470 L ha^{-1} (Table 8). Genotype BRS 506 presented the best estimate for ethanol yield, while genotype CV 147 presented the highest fiber yield. In energy terms, adding fiber and ethanol, genotype BRS 506 presented the best result (104108.10 MJ ha^{-1}), followed by CV 147 (93815.18 MJ ha^{-1}). This was reflected in the energy balance (produced/ used), and genotype BRS 506 showed the best efficiency ratio (4.24), followed by CV 147 (3.80). The lowest ratio between energy produced/energy used was for genotype CV 007 (3.63).

TABLE 8. Energy balance - irrigated treatment.

Agricultural production	BRS 506	CV 007	CV 147	EJ 7281
Alcohol* (L ha^{-1})	4,470	3,760	3,977	3,904
Fiber (ton ha^{-1})	9,687	9,262	9,940	9,707
Energy production (MJ ha^{-1})				
Alcohol**	95,389.80	80,238.40	84,869.18	83,311.36
Fiber excess (5%) ***	8,718.30	8,335.80	8,946.00	8,736.30
Agricultural phase (MJ ha^{-1})	21,379.05	21,379.05	21,379.05	21,379.05
Industrial phase (MJ ha^{-1})	3,150.93	3,002.70	3,311.85	3,180.57
Energy balance				
Alcohol	3.89	3.29	3.44	3.39
Alcohol + fiber (5%)	4.24	3.63	3.80	3.75

*Alcohol = yield of 0.565 kg of ethanol per kg of sugar (Finguerut et al. 2008), ** Alcohol = 21.34 MJ L^{-1} (EPE, 2014), *** Fiber = 18 MJ kg^{-1} (Tolmasquim 2006).

The ethanol production estimate ranged from 1797 to 2438 L ha^{-1} in the rainfed condition (Table 9), while fiber yield ranged from 5.101 to 6.042 t ha^{-1}. Regarding the placement by productivity (sugar, fiber, and energy), the same trend was observed for the irrigated treatment, and genotypes BRS 506 and CV 147 presented the highest values. With this, the genotype BRS 506 obtained the best energy balance (3.38), followed by genotype CV 147 (3.28), but the difference was smaller, slightly more than 3%. In the irrigated treatment, the difference between the two genotypes was almost 12%.

TABLE 9. Energy balance - rainfed condition.

Agricultural production	BRS 506	CV 007	CV 147	EJ 7281
Alcohol* (L ha^{-1})	2,438	1,979	2,377	1,797
Fiber (ton ha^{-1})	5.849	5.331	6.042	5.101
Energy production (MJ ha^{-1})				
Alcohol**	52,026.92	42,231.86	50,725.18	38,347.98
Fiber excess (5%)	5,264.10	4,797.90	5,437.80	4,590.90
Agricultural phase (MJ ha^{-1})	15,105.86	15,105.86	15,105.86	15,105.86
Industrial phase (MJ ha^{-1})	1,833.80	1,838.05	2,015.93	1,710.97
Energy balance				
Alcohol	3.07	2.49	2.96	2.28
Alcohol + fiber (5%)	3.38	2.78	3.28	2.55

* Hydrated alcohol = yield of 0.465 L of ethanol per kg of sugar (Finguerut et al., 2008), ** Hydrated Alcohol = 21.34 MJ L^{-1} (EPE, 2014), *** Fiber (FIB) = 18 MJ Kg^{-1} (Tolmasquim 2006).

The high yields achieved under irrigated conditions allowed for high energy gains fulfilling the higher energy demand in this treatment, when compared to the rainfed. There was an increase in energy balance (energy produced/energy used) for all treatments. The highest increase was for genotype EJ 7281 (47.05%), followed by CV 007 (30.57%), and BR 506 (25.44%). The lowest increase was for genotype CV 147 (15.85%), which responded well to the rainfed condition.

Compared to the case of Brazilian ethanol, in which the energy/fossil energy extraction rate used is around 8.3 (BNDES & CGEE, 2008), the ratio obtained for the alcohol produced from sugar sorghum is still well smaller. In the present study, this ratio was on average 3.5 for the irrigated condition, and 2.8 for the rainfed condition, which indicates sorghum as a competitor crop with sugarcane, but rather be an alternative in the off-season. However, sorghum is competitive when compared to other species. Ethanol from corn produced in the United States has an energy balance of 1.3 (BNDES & CGEE, 2008). Cassava has a ratio of 1.76 (Adelekan, 2012). Oleaginous plants used for the production of biodiesel, sunflower and soybean, considered as options for reforestation of sugarcane areas, have energy balance values of 2.37 and 3.95, respectively (Gazzoni et al., 2005).

Even though these crops require specific equipment and methods for biofuel production, sorghum undergoes the same processing as sugarcane.

CONCLUSIONS

Sorghum cultivation in the Dourados region presents a positive energy balance in both rainfed and irrigated conditions. The highest energy balance values are observed in the irrigated crop, due to the higher yields of stems and alcohol.

REFERENCES

Adelekan BA (2012) Cassava as a Potent Energy Crop for the Production of Ethanol and Methane in Tropical Countries. International Journal of Thermal & Environmental Engineering 4(1):25-32.

Almeida JRM, Fávaro LCL (2011) Sorgo sacarino: tecnologia agronômica e industrial para alimentos e energia. Leveduras para produção de etanol de sorgo sacarino**.** Agroenergia em revista. Brasília, Embrapa, 3ed. p29-30.

Assenheimer A, Campos AT, Gonçalves Júnior AFC (2009) Análise energética de sistemas de produção de soja convencional e orgânica. Ambiência. Revista do Setor de Ciências Agrárias e Ambientais 5(3):443-455.

Azevedo MS, Santos RVO, Magalhães TV (2012) Produção de etanol no Brasil. Revista de divulgação do Projeto Universidade Petrobras e IF Fluminense 2:151-154.

Banchi AD, Lopes JR, Ferreia VAC, Scaranelo LTA (2012) Análise de reforma de colhedoras de cana-de-açúcar. Revista AgriMotor:40-43.

BNDES; CGEE (2008) Bioetanol de cana-de-açúcar: Energia para o desenvolvimento sustentável. Coordenação do Banco Nacional de Desenvolvimento Econômico e Social e do Centro de Gestão e Estudos Estratégicos. Available: http://www.bioetanoldecana.org/pt/download/bioetanol.pdf . Accessed: Jun, 2014.

Borges ID, Mendes AA, Viana EJ, Gusmão CAG, Rodrigues HFF, Carlos LA (2010) Caracterização do caldo extraído do colmo da cultivar de sorgo sacarino BRS 506 (*Sorghum bicolor* L.). In: Congresso Nacional de Milho e Sorgo. Goiânia, Associação Brasileira de Milho e Sorgo, Anais…

Camacho R, Malavolta E, Gueireiro-Alves J, Camacho T (2002) Vegetative growth of grain sorghum in response to phosphorus nutrition. Scientia Agrícola 59(4):771-776.

Checheto RG, Siqueira R, Gamero CA (2010) Balanço energético para a produção de biodiesel pela cultura da mamona (*Ricinus communis* L.). Revista Ciência Agronômica 41(4):546-553.

Cunha SP, Severo Filho WA (2010) Avanços tecnológicos na obtenção de etanol a partir de sorgo sacarino (Sorghum bicolor (L.) Moench). TECNO-LÓGICA 14(2):69-75.

Durães FOM (2011) Agroenergia em revista Sorgo sacarino: tecnologia agronômica e industrial para alimentos e energia. Sorgo sacarino: desenvolvimento de tecnologia agronômica. Agroenergia em revista. Brasília, Embrapa, 3ed. p7.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária Embrapa Milho e Sorgo (2012) Sistema Embrapa de Produção Agroindustrial de Sorgo Sacarino para Bioetanol Sistema BRS1G – Tecnologia Qualidade Embrapa. Embrapa.

EPE – Empresa de Pesquisa Energética (Brasil) (2014) Balanço Energético Nacional 2014: Ano base 2013 / Empresa de Pesquisa Energética. Rio de Janeiro, EPE, 288p.

Fernandes PG, May A, Coelho FC, Abreu MC, Bertolino KM (2014) Influência do espaçamento e da população de plantas de sorgo sacarino em diferentes épocas semeadura. Ciência Rural 44(6):975-981.

Finguerut J, Meirelles AJA, Guirardello R, Costa AC (2008) Fermentação, hidrólise e destilação. In: Cortez LAB, Lora ES, Olivarez Gómez E. Biomassa para energia. Editora da Unicamp, cap13, p435-473.

Frizzone JA, Andrade Junior AS, Souza JLM, Zocoler JL (2005) Análise de projetos de irrigação e drenagem. In: Planejamento de irrigação. Brasília, EMBRAPA, p17-53.

Gazzoni DL, Felici PHN, Coronato RMS, Ralisch R (2005) Balanço energético das culturas de soja e girassol para produção de biodiesel. Biomassa e Energia 2(4):259-265.

Jordan RA, Gomes EP, Biscaro GA (2012a) Impact of irrigation on yield and energy balance of the production of oil and cake of two sunflower genotypes. Engenharia Agrícola 32(6):1048-1057.

Jordan RA, Gomes EP, Biscaro GA, Motomiya AVA, Geisenhoff L (2012b) Impacto energético da irrigação por gotejamento no cultivo de mamona. Pesquisa Agropecuária Tropical 42(4):375-382.

Kamphorst JS (2003) Quanto gasta seu trator. Revista Cultivar Máquinas 2(24):8-11.

Kohlhepp G (2010) Análise da situação da produção de etanol e biodiesel no Brasil. Estudos avançados 24(68):223-253.

Lyra GA (2012) Consumo de combustível de duas colhedoras de cana-de-açúcar em função da velocidade e rotação de motor. Dissertação, Botucatu, Universidade Estadual Paulista Júlio de Mesquita Filho, 53p.

Moreira LR (2010) Biocombustíveis: abastecer o debate sobre os rumos da política energética. Revista Princípios 105:50-54.

Munyinda K, Yamba FD, Walimwipi R (2012) Bioethanol Potential and Production in Africa: Sweet Sorghum as a Complementary Feedstock. Bionergy for sustainable development in Africa:81-91 DOI: http://dx.doi.org/10.1007/978-94-007-2181-4_8

Pacheco EP (2000) Seleção e custo operacional de máquinas agrícolas. Rio Branco, Embrapa Acre. 21p.

Pereira Filho IA, Parrella RAC, Moreira JAA, May A, Souza VF, Cruz JC (2013) Avaliação de cultivares de sorgo sacarino [*sorghum bicolor (l.) moench*] em diferentes densidades de semeadura visando a características importantes na produção de etanol. Revista Brasileira de Milho e Sorgo 12(2):118-127.

Purcino AAC (2011) Sorgo sacarino: tecnologia agronômica e industrial para alimentos e energia. Sorgo sacarino na Embrapa: histórico, importâncias e usos. Brasília, Embrapa, 3ed. p6.

Saturnino HM, Christofidis D, Costa EL, Reis JBS (2010) Agricultura irrigada: Oportunidades e desafios. Informe Agropecuário 31:101-109.

Tolmasquim MT (2006) Civilização da biomassa - Matriz energética. Ciclo Temático Civilização da Biomassa. Instituto de Estudos Avançados da Universidade de São Paulo. Available: http://www.iea.usp.br/midiateca/apresentacao/tolmasquimmatriz.pdf/at_download/file. Accessed: Nov 12, 2014.

Uribe RAM, Ticianeli CST (2014) Influência do estande na produtividade do sorgo sacarino. Dialogos & Ciência 34(14):10-12. Available: http://periodicos.ftc.br/index.php/dialogos/article/view/10/pdf_2. Accessed: Dec 16, 2014.