Scientia Agricola

Technical and economic assessment of trash recovery in the sugarcane bioenergy production system

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Edited by: Heitor Cantarella

Received September 18, 2012
Accepted July 11, 2013

ABSTRACT: Mechanized sugarcane (*Saccharum* spp.*)* harvest without burning has been increasingly adopted in Brazil, increasing trash availability on the field. This study aims at showing the importance of using an integrated framework tool to assess technical and economic impacts of integral harvesting and baling trash recovery strategies and different recovery rates as well as its implications in the sugarcane production, transport and processing stages. Trash recovery using baling system presents higher costs per unit of mass of recovered trash in comparison to system in which trash is harvested and transported with sugarcane stalks (integral harvesting system). However, the integrated agricultural and industrial assessment showed that recovering trash using baling system presents better economic results (higher internal rate of return and lower ethanol production cost) than the integral harvesting system for trash recovery rates higher than 30 %. Varying trash recovery fraction, stalks productivity and mean transport distance for both integral harvesting and baling systems, sensitivity analyses showed that higher trash recovery fractions associated with higher stalks yields and long transport distances favors baling system, mainly due to the reduction of bulk load density for integral harvesting system under those conditions.

Introduction

Mechanized sugarcane (*Saccharum* spp.) harvest without burning has been increasingly adopted in Brazil, mainly due to environmental and legal issues (Fortes et al., 2012), and labor shortage. There are several benefits of trash left on soil surface, such as nutrient recycling (Oliveira et al., 1999); increase in soil carbon sequestration (Cerri et al., 2011), greenhouse gases emissions reduction (Galdos et al., 2013), weed infestation reduction (Monquero et al., 2008) and sugarcane yield increase (Gava et al., 2001). On the other hand, the maintenance of large amounts of trash on the soil surface can also result in some negative impacts such as the reduction of ratoon sprouting, increase risk of fire (Rossetto et al., 2008), greater incidence of sugarcane insects (Macedo et al., 1997), and difficulties in the mechanized cultivation (Magalhães et al., 2012). Recently, the interest on using sugarcane trash as fuel for heat and power, and also for second generation ethanol has grown (Leite et al., 2009; Dias et al., 2012; Seabra et al., 2010; Suramaythangkoor and Li, 2012). However, large scale use of these residues is still hampered by high recovery costs related to gathering, baling, transportation, chopping and residue utilization technology (Michelazzo and Braunbeck, 2008).

In unburned sugarcane harvest, large amounts of residues are left on the field, ranging from 10 to 20 t ha^{-1} of dry matter depending on topping height, sugarcane variety and yield, crop age, climate, type of soil and other factors (Magalhães et al., 2012). Furthermore, both agronomic and industrial benefits and drawbacks must be evaluated to support the main current question related to this issue: How much trash can be removed from sugarcane fields and still improve sustainability of sugarcane production chain?

To assess all these aspects, the Virtual Sugarcane Biorefinery (VSB) is being constructed in order to evaluate technical, economic and environmental parameters of different biorefinery alternatives considering the entire sugarcane production chain (Cavalett et al., 2012; Dias et al., 2012). This study of trash recovery highlights the importance of using an integrated assessment framework to evaluate technical and economic impacts of integral harvesting and baling strategies for different recovery rates as well as its implications for the sugarcane production, transport and processing operations.

Materials and Methods

The two main management systems for trash recovery were evaluated: Integral harvesting system – Trash is harvested, chopped and transported together with the sugarcane stalks without laying it down to the ground for natural drying. At the industry, trash is (partially) separated from stalks using an air separation system (dry cleaning station) (Hassuani et al., 2005); Baling system – Trash is left on the field for about 15 days after sugarcane harvesting to decrease its water content through natural drying. After the windrowing of trash, a tractor-propelled baler collects and compresses the trash. After grab loading, the bales are transported by trucks to the industry (Hassuani et al., 2005).

For each of these two systems, three fractions of trash recovery were evaluated. Removing 100 % of trash is considered unfeasible in both scenarios. In the integral harvesting system, part of the trash falls on the soil before and during the harvest operation, while in the baling system is technically and economically unfeasible to collect all the trash present on the soil surface. Therefore, only recovery fractions of 30 %, 50 % and 70 % of the total amount of trash were evaluated and compared to a scenario without trash recovery. In this way, seven scenarios were considered (Table 1).

Agricultural phase

To assess the agricultural phase it was used the CanaSoft model, a computational tool, which has been developed at the Brazilian Bioethanol Science and Technology Laboratory (CTBE) for simulation of important parameters for technical and sustainability assessment of agricultural practices in the sugarcane production chain. This model was developed on spreadsheets and integrates several calculation modules. It contains an interface in which the main parameters of production are defined (yield, planting and harvesting systems, fertilizer doses, among others factors). These parameters are considered for the life cycle inventory calculation and also for economic assessment. Both economic and inventory calculation are linked to an agricultural database which involves the information about all agricultural operations used in sugarcane production such as agricultural performance parameters, types of harvesters, tractor and implements, as well as their weight, costs, diesel consumption, annual use, life span and depreciation, among other parameters.

The basic assumptions for this study were:

- sugarcane yield of 83 t ha^{-1}tons of sugarcane stalks, average yield of plant cane and four ratoons (IBGE, 2013); 140 kg t^{-1} of trash (dry basis) per mass of stalks (Ripoli and Ripoli, 2009; Hassuani et al., 2005);
- mechanized planting using 20 t ha^{-1}of seed cane; planting every five harvesting seasons;
- totally mechanized harvesting was considered without pre-harvest burning;
- sugarcane transport trucks with volumetric capacity of 184 m³ and the mean transport distance between field and industry of 30 km. The sugarcane transport density varies according to the trash recovery system.

Table 1 – Description of evaluated scenarios.

Scenario	Description
Base	Without trash recovery
I30	Integral harvesting system, with 30 % of trash recovery
I50	Integral harvesting system, with 50 % of trash recovery
I70	Integral harvesting system, with 70 % of trash recovery
B30	Baling system, with 30 % of trash recovery
B50	Baling system, with 50 % of trash recovery
B70	Baling system, with 70 % of trash recovery

Main agricultural inputs for the different evaluated scenarios are shown in Table 2 as well as the amount of trash recovered in each alternative, with its moisture and nutrients exported to the industry. For the integral harvesting system the trash composition (nutrients and moisture) were based on data from Franco et al. (2012). It was also considered that final trash moisture is the same as that observed by Ripoli and Ripoli (2009) for dry leaves. For baling system, it was assumed that 50 % of the potassium present on tops is recycled during the period that trash remains in field. As the potassium is present in ionic form in sugarcane cells, it is released after rupture of cell membrane and can be used by next ratoon (Franco et al., 2007; Malavolta et al., 1997). In this study, it was assumed that the potassium exported by removal of different amount of trash is replaced by commercial fertilizer. As a result, higher fractions of trash removal increase fertilizer application in sugarcane field.

It was considered that the same amount of nitrogen applied as commercial fertilizer in all the scenarios because the mineralization of nitrogen is substantially slower compared to that of potassium and the recovery rates of N by ratoon from crop residues incorporated into the soil varied from 2 % to 15 % of the total N contained in such residues (Ambrosano et al., 2005; Fortes et al., 2012; Gava et al., 2005; Meier et al., 2006; Trivelin et al., 2002; Vitti et al., 2010).

In the baling system, after approximately 15 days in the field, trash is windrowed, baled and transported separately from sugarcane stalks to the industry. It was considered that the fractions recovered in scenarios B30, B50 and B70 can be obtained with adjustments in the trash windrower.

For integral harvesting system, it was considered that different fractions of trash recovery are possible to be obtained after adjusting the primary blower of the harvester. The harvest of trash along with sugarcane stalks leads to lower load density in the transport trucks, affecting operational capacity of the transport. The magnitude of these reductions in loading density was estimated based on correlations by Hassuani et al. (2005) and are also detailed in Table 2. The diesel consumption was calculated for each mechanized operation considering data related to agricultural performance, engine power, power use factor, maintenance, management and operational efficiencies, beyond other factors which affect diesel consumption and are modeled on CanaSoft.

Industrial phase

In this study, an optimized autonomous distillery with maximization of surplus electricity taken into account (all the bagasse and trash is used as fuels to supply the energy demand and for electricity production) (Dias et al., 2011). Mass and energy balances for the industrial configurations were obtained through computer simulations of the different industrial scenarios using the software Aspen Plus® (Cavalett et al., 2012; Dias et al., 2012).

Table 2 – Agricultural inputs for different trash recovery scenarios.

Parameter	Unit	Scenario						
		Base	I30	I50	I70	B30	B50	B70
Trash recovered (dry basis)	t ha^{-1}	0	3.5	5.8	8.1	3.5	5.8	8.1
Tops	t ha^{-1}	0	0.0	0.0	1.9[a]	1.6[b]	2.7[b]	3.7[b]
Dry leaves	t ha^{-1}	0	3.5	5.8	6.3	1.9	3.1	4.4
Trash moisture	%	-	8.8	8.8	20.9	8.8	8.8	8.8
Nutrients exported with recovered straw								
N	kg ha^{-1}	0	11.9	19.8	35.3	18.4	30.7	43.0
P_2O_5	kg ha^{-1}	0	1.4	2.3	6.1	3.9	6.5	9.1
K_2O	kg ha^{-1}	0	7.6	12.6	41.4	16.1	26.8	37.5
Fertilizers application (ratoons)								
N	kg ha^{-1}	120	120	120	120	120	120	120
P_2O_5	kg ha^{-1}	0	0	0	0	0	0	0
K_2O	kg ha^{-1}	120	127.6	132.6	161.4	136.1	146.8	157.5
Agricultural inputs								
Fertilizers (total mass)	kg ha^{-1} y^{-1}	611	618	622	646	625	634	643
Agrochemicals	kg ha^{-1} y^{-1}	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Limestone	kg ha^{-1} y^{-1}	474	474	474	474	474	474	474
Gypsum	kg ha^{-1} y^{-1}	237	237	237	237	237	237	237
Vinasse	m^3 ha^{-1} y^{-1}	67	67	67	67	67	67	67
Filtercake	kg ha^{-1} y^{-1}	2216	2216	2216	2216	2216	2216	2216
Ashes	kg ha^{-1} y^{-1}	498	498	498	498	498	498	498
Seedlings	t ha^{-1} y^{-1}	4.7	4.7	4.7	4.7	4.7	4.7	4.7
Diesel consumption								
Planting and cultivation	L ha^{-1} y^{-1}	87.4	87.4	87.4	87.4	87.4	87.4	87.4
Harvesting	L ha^{-1} y^{-1}	101.6	101.6	101.6	101.6	101.6	101.6	101.6
Transloader	L ha^{-1} y^{-1}	68.1	68.1	68.1	68.1	68.1	68.1	68.1
Windrowing	L ha^{-1} y^{-1}	0.0	0.0	0.0	0.0	5.1	5.1	5.1
Baling	L ha^{-1} y^{-1}	0.0	0.0	0.0	0.0	21.7	26.1	32.5
Bales loading	L ha^{-1} y^{-1}	0.0	0.0	0.0	0.0	21.0	21.0	21.0
Sugarcane transport	L ha^{-1} y^{-1}	87.3	112.6	132.7	154.6	87.3	87.3	87.3
Bales transport	L ha^{-1} y^{-1}	0.0	0.0	0.0	0.0	8.9	14.9	20.8
Truck load per trip								
Stalks + Trash	t truck^{-1} trip^{-1}	60 + 0	45.6 + 2.1	38.7 + 3	33.2 + 4.1	60 + 0	60 + 0	60 + 0
Bales	t truck^{-1} trip^{-1}	0.0	0.0	0.0	0.0	26.5	26.5	26.5

[a]In the integral harvesting system, sugarcane tops are preferentially left in the field due to its higher water and nutrients content. However, since sugarcane tops correspond to 46 % of total trash, when 70 % of trash is recovered a fraction of tops are also recovered; [b]In the baling system, both sugarcane tops and dry leaves are first left in the field and are consequently mixed; therefore the trash recovery using the baling system always recover the same proportional fraction of sugarcane tops and dry leaves.

The technical parameters for ethanol production in an optimized autonomous distillery are detailed in Cavalett et al. (2012). At the industrial site, trash resulting from integral sugarcane harvesting is separated by an air separation system (dry cleaning station) because more trash passing through the mill along with sugarcane stalks promotes reduction in the sugar separation efficiency and crushing capacity. For this separation, of trash from stalks, one considered an efficiency of 70 % according to industrial information (Souza, 2012). For both Base and baling system scenarios (B30, B50 and B70), it was considered a separation of juice (sugar) from fiber (bagasse) efficiency of 96.0 %. Reduction in separation of juice from fiber (bagasse + residual trash) efficiency was considered as 95.1 %, 94.5 % and 93.8 % for the scenarios I30, I50 and I70, respectively, based on Camargo et al. (1990).

In the trash recovery by baling system, a higher incorporation of mineral impurities was assumed as the higher fraction of trash is removed, since more soil is collected with the trash that is in contact with soil. According to Ripoli (2004), the fraction of mineral impurities increases proportionally to the amount of trash recovered. The fractions considered are 2 %, 4 % and 8 % of mineral impurities for the scenarios B30, B50 and B70, respectively (Ripoli and Ripoli, 2009; Mello, 2009; Perea et al., 2012). Higher mineral impurities cause a small decrease in the trash calorific value due less lignocellulosic material per volume (Magalhães and Braunbeck, 2010). Other negative effects due to increased mineral impurities in the lignocellulosic material used in the industrial stage such as boiler and blower maintenance and the removal of topsoil rich in organic matter and nutrients were not considered in this study due to lack of data.

Economic analysis

The amounts of anhydrous ethanol and surplus electricity produced were obtained for each scenario based on the results of the industrial process computer simulations using the VSB tool. Sugarcane total production cost with different trash recovery alternatives was calculated using the economic module of CanaSoft model in the VSB. These results, along with industrial operational and investment costs, were employed to perform economic analysis, through the determination of internal rate of return (IRR) and production costs using conventional methods of economic viability assessment. Ethanol and electricity levelized production costs were obtained through a proportional reduction of their prices, until the IRR is zero. In this condition, capital expenditure is recovered and there is no return on capital invested.

Concerning the economic analysis, the following other assumptions were made:

- entire agricultural area required for the sugarcane processed belongs to the mill and an annual opportunity cost (leasing) for this land is included in the analysis;
- the industrial plant life includes 2 years for construction and start-up plus 25 years of full production capacity;
- value of the plant at the end of the project was considered to be zero;
- sugarcane and trash recovery agricultural production costs were calculated considering a detailed assessment of all the inputs (tractors, implements, harvesters, fuel, labor, fertilizers, agrochemicals, among others) used for its production in the agricultural phase and its transport to the mill;
- ethanol and electricity market prices were assumed as 0.53 US$ L^{-1} (average of last ten years) and 74.67 US$ MWh^{-1} (average of last six public auctions for renewable electricity in Brazil) respectively (Dias et al., 2012).

Industrial economic parameters considered for different trash recovery scenarios are shown in Table 3.

Results and Discussion

Trash recovery costs

Table 4 shows the sugarcane production costs for different trash recovery alternatives. Trash recovery costs are calculated as the additional costs (per hectare) of each trash recovery scenario in comparison to the Base scenario (without trash recovery). Sugarcane (and trash) production costs are presented per hectare and per mass of harvested sugarcane stalks, whilst trash recovery costs are presented per mass of removed trash and also the additional cost per mass of harvested sugarcane stalks compared with the Base scenario.

Higher rates of trash removal indicate higher sugarcane (and trash) production costs per area in all scenarios, due to higher costs to collect and transport more trash. However, the trends in the trash recovery costs to increased trash recovery rates are not the same for the two recovery systems evaluated in this study (Figure 1). For sugarcane stalks yield of 83 t ha^{-1} and mean transport distance of 30 km, integral harvesting system is economically favorable (considering only the trash recovery cost) in comparison to the baling system. Those results are in accordance with Hassuani et al. (2005) and Michelazzo and Braunbeck (2008). For small rates of trash recovery Hassuani et al. (2005) have verified that integral harvest is better than baling. However, the cost of integral harvest increases when large amounts of trash are transported with sugarcane stalks (trend in Figure 1). Considering 50 % of trash recovery, Michelazzo and Braunbeck (2008) concluded that baling system presented higher costs than integral harvest.

Based on the detailed economic model developed to assess the different trash recovery alternatives, a sensitivity analysis was made (Figure 2). Varying the stalks yield (70 t ha^{-1}, 83 t ha^{-1} and 95 t ha^{-1}) and mean transport distance (20 km, 30 km, 60 km and 85 km), for each stalks yield the distance was estimated for which the trash recovery costs were the same for integral harvesting and baling systems. For any point below the curves integral harvesting system presents lower costs than baling system, and, conversely, for points above the curves, baling system is better than integral harvesting (Figure 2). Higher trash recovery frac-

Table 3 – Industrial economic parameters for different trash recovery scenarios.

Parameter	Scenario						
	Base	I30	I50	I70	B30	B50	B70
Investment (MM US$)							
Reception, preparation and juice extraction	24.44	29.52	29.52	29.52	24.77	24.77	24.77
Steam generation, electricity and industrial power system	41.12	49.92	55.26	59.95	50.23	55.74	60.91
Other investments	135.43	135.43	135.43	135.43	135.43	135.43	135.43
Annual costs (MM US$)							
Sugarcane stalks and trash	51.89	53.79	55.26	57.31	55.70	56.78	57.99
Labor, other inputs and basic maintenance	17.01	17.53	17.93	18.49	18.05	18.34	18.67
Taxes	0.67	0.73	0.76	0.79	0.73	0.77	0.81
Annual revenues (MM US$)							
Ethanol	89.85	88.97	88.38	87.80	89.86	89.85	89.85
Electricity	13.55	22.65	28.72	34.30	22.94	29.20	35.47

Table 4 – Sugarcane and trash production costs calculated for the different scenarios.

Production costs	Unit	Scenario						
		Base	I30	I50	I70	B30	B50	B70
Agricultural operations								
Tractors	US\$ ha^{-1} y^{-1}	90.62	90.62	90.62	90.62	117.25	119.01	121.63
Balers	US\$ ha^{-1} y^{-1}	0.00	0.00	0.00	0.00	13.24	15.87	19.81
Other agricultural implements	US\$ ha^{-1} y^{-1}	88.57	88.57	88.57	88.57	88.75	88.75	88.75
Harvesters	US\$ ha^{-1} y^{-1}	103.21	103.21	103.21	103.21	103.21	103.21	103.21
Diesel	US\$ ha^{-1} y^{-1}	261.11	261.11	261.11	261.11	309.66	314.05	320.61
Maintenance, lubricants and taxes	US\$ ha^{-1} y^{-1}	39.97	39.97	39.97	39.97	47.20	47.84	48.80
Labor	US\$ ha^{-1} y^{-1}	109.41	109.41	109.41	109.41	118.71	119.30	120.19
Sugarcane and trash transport								
Trucks	US\$ ha^{-1} y^{-1}	98.46	128.11	151.00	175.98	112.39	121.67	130.96
Diesel	US\$ ha^{-1} y^{-1}	88.68	114.28	134.70	156.99	97.75	103.79	109.84
Maintenance, tires and taxes	US\$ ha^{-1} y^{-1}	39.23	50.61	59.65	69.53	43.35	46.09	48.83
Labor	US\$ ha^{-1} y^{-1}	18.57	24.40	28.76	33.52	21.40	23.29	25.18
Inputs								
Seedlings	US\$ ha^{-1} y^{-1}	157.85	157.85	157.85	157.85	157.85	157.85	157.85
Syntetic fertilizers	US\$ ha^{-1} y^{-1}	335.14	341.06	344.96	367.42	347.69	356.04	364.38
Agrochemicals	US\$ ha^{-1} y^{-1}	110.09	110.09	110.09	110.09	110.09	110.09	110.09
Limestone and gypsum	US\$ ha^{-1} y^{-1}	20.64	20.64	20.64	20.64	20.64	20.64	20.64
Wires (for bales)	US\$ ha^{-1} y^{-1}	0.00	0.00	0.00	0.00	9.41	15.68	21.96
Inputs transport	US\$ ha^{-1} y^{-1}	49.10	49.20	49.27	49.67	49.32	49.47	49.61
Vinasse application	US\$ ha^{-1} y^{-1}	62.70	62.70	62.70	62.70	62.70	62.70	62.70
Land	US\$ ha^{-1} y^{-1}	392.84	392.84	392.84	392.84	392.84	392.84	392.84
Taxes	US\$ ha^{-1} y^{-1}	74.15	74.15	74.15	74.15	74.15	74.15	74.15
Total	US\$ ha^{-1} y^{-1}	2140.34	2218.84	2279.52	2364.28	2297.60	2342.33	2392.04
Sugarcane stalks yield (wet basis)	t ha^{-1}	83.00	83.00	83.00	83.00	83.00	83.00	83.00
Trash recovered (dry basis)	t ha^{-1}	0.00	3.49	5.81	8.13	3.49	5.81	8.13
Cost per tonne of sugarcane stalks	US\$ t^{-1}	25.79	26.73	27.46	28.49	27.68	28.22	28.82
Additional cost per tonne of sugarcane stalks	US\$ t^{-1}	0.00	0.95	1.68	2.70	1.89	2.43	3.03
Cost per tonne of trash	US\$ t^{-1}	0.00	22.52	23.95	27.53	45.11	34.77	30.94

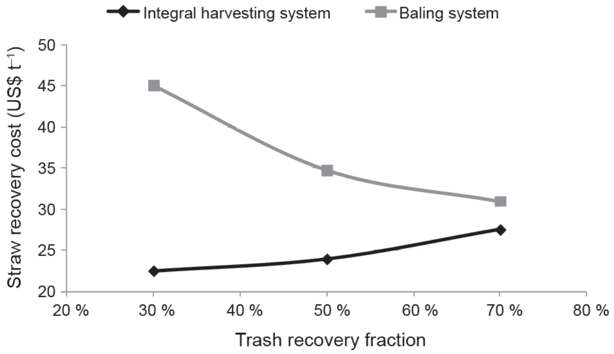

Figure 1 – Trends in the trash recovery costs for different trash recovery rates.

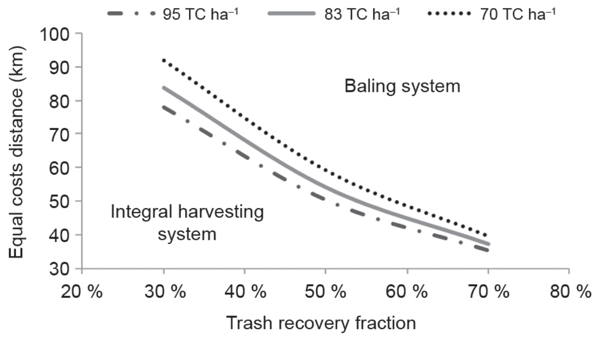

Figure 2 – Sensitivity analysis for integral and baling systems costs depending on sugarcane yield and distance from field to the mill.

tions associated with higher stalk yields and long transport distances favors baling system, mainly due to the reduction of bulk load density for integral harvesting system under those conditions. However, when trash is chopped by the sugarcane harvester, the effect of density reduction would be lower and integral harvesting with trash chopped might be advantageous even under these conditions.

Integrated agricultural and industrial economic analysis

Larger trash recovery rates promote higher electricity surplus, which can be sold to the grid. The integral harvesting system resulted in lower ethanol production than baling system due to higher sugar losses during the extraction operation in the industrial plant (Figure 3). The larger amount of trash processed through the mill also causes higher energy consumption (due to larger amount of material to be crushed). Hence, there is lower electricity surplus in the integral harvesting system scenarios compared to baling system scenarios.

For baling and integral harvesting systems, the economic results showed that the higher the fraction of recovered trash, the better the economic performance of the process (Figure 4). The reduction on ethanol production cost follows the trend of increasing IRR.

The IRR upward trend was more pronounced for baling system scenarios in comparison to integral harvesting ones (Figure 4). This takes place because increasing the cost in the integral harvesting system is proportional to the increasing amount of trash loaded due to a lower bulk density of the transported material, accentuated when transporting some of the tops with higher moisture as in scenario I70. Furthermore, investment in dry cleaning station causes a negative impact on IRR for integral harvesting scenarios. Nevertheless, in the baling system scenarios, higher trash recovery rates promotes higher electricity output and hence, higher IRR and lower ethanol production cost.

The results indicated that the best option in economic terms for higher trash recovery fractions is the baling system. All the scenarios with trash recovery are able to decrease the ethanol production costs in comparison to the Base scenario. This is very important from the consumer point of view, which can benefit from a biofuel with lower production costs, but also from the demand side that can be stimulated by an ethanol with more competitive prices in comparison to gasoline.

A sensitivity analysis for IRR similar to the one presented in Figure 2 varying stalks productivity (70 t ha^{-1}, 83 t ha^{-1} and 95 t ha^{-1}) and mean transport distance (20 km, 30 km, 60 km and 85 km) was performed considering the integrated agricultural and industrial assessment (Table 5). Similarly to the one presented for the trash recovery costs, higher IRRs are obtained for scenarios with baling system in comparison with integral harvesting system for higher stalks productivities and longer transport distances.

Sensitivity analysis varying trash recovery fractions, stalks productivity and mean transport distance for both integral harvesting and baling systems showed that higher trash recovery fractions associated with higher stalks productivities and long transport distances favors

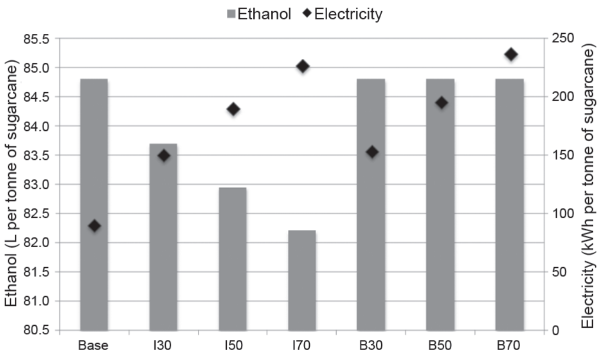

Figure 3 – Ethanol and surplus electricity production considering the different alternatives for trash recovery (See Table 1 for scenarios description).

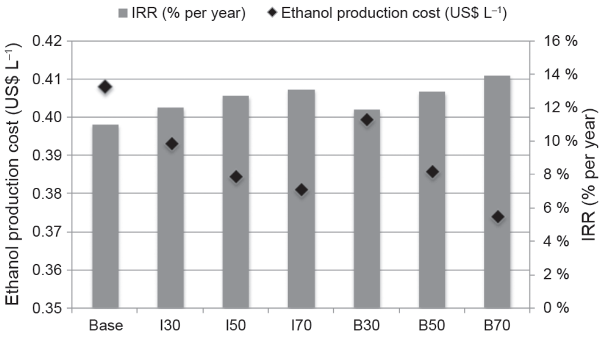

Figure 4 – Comparison of ethanol production costs and IRR considering the different alternatives for trash recovery (See Table 1 for scenarios description).

Table 5 – Sensitivity analysis for IRR (%).

Sugarcane yield (t ha^{-1})	Transport distance (km)	Scenario						
		Base	I30	I50	I70	B30	B50	B70
70	20	8.24	9.75	10.73	10.98	9.29	10.59	11.72
	30	7.42	8.82	9.71	9.83	8.48	9.79	10.95
	60	4.37	5.69	6.27	5.88	5.75	7.18	8.40
	85	0.76	1.56	1.84	0.42	2.29	4.35	5.97
83	20	11.68	12.80	13.61	13.83	12.56	13.64	14.61
	30	10.98	11.98	12.70	12.80	11.85	12.94	13.91
	60	8.74	9.34	9.75	9.41	9.58	10.69	11.67
	85	6.58	6.77	6.83	5.99	7.41	8.56	9.57
95	20	13.76	14.68	15.40	15.61	14.56	15.53	16.42
	30	13.11	13.91	14.54	14.63	13.89	14.87	15.75
	60	11.02	11.42	11.74	11.42	11.76	12.73	13.60
	85	9.16	9.17	9.18	8.44	9.86	10.84	11.72

baling system, mainly due to the reduction of bulk load density for integral harvesting system under those conditions. It is important to highlight that some of the negative effects of mineral impurities in the industrial plant, as well as the possibility of an increase on the efficiency of the dry cleaning station, were not considered in this analysis; these consideration can reduce the economic advantages of the baling system. The analysis performed in this study did not take into consideration the predominantly beneficial but also some of the negative effects of trash preservation discussed early in this text. These effects are usually site-specific and not well defined at the moment (see other articles in this Special Issue).

Conclusions

Trash recovery using the baling system presents higher costs per unit of mass of trash recovered in comparison to system where trash is harvested and transported together with sugarcane stalks (integral harvesting system). However, the integrated agricultural and industrial assessment showed that scenarios recovering trash using the baling system present better economic results (higher IRR and lower ethanol production cost) than the integral harvesting system for straw recovery fractions higher than 30 % (considering sugarcane stalks yield of 83 t ha^{-1} and mean transport distance of 30 km).

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