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Chapter 5

Competitive Management of Sugarcane Waste and Reduction of CO_2 Emissions from Harvest Burning in Supply Regions

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Additional information is available at the end of the chapter

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Abstract

Sugarcane is an important crop in more than 100 countries around the world. Their burning is a cultural activity before and after the harvest; however, pollutants and greenhouse gases emitted to the atmosphere can affect the human health and weather, respectively. The aim of this research is to report the CO_2 emissions of the main countries dedicated to the cane production and explain their relevant relation with the dry matter available to the burn and how it can affect their alternative uses. The methodology used in this study identifies the relation between biomass burned (dry matter) and CO_2 emissions, estimated by the Food and Agriculture Organization of the United Nations with the techniques of the Intergovernmental Panel on Climate Change. The study was carried out for the period of 1990–2014. The results show an important positive trend in the increase in the annual production levels and the biomass burned during the harvest period. The high correlation between harvested area and yield per hectare in countries such as Brazil and the United States allows to have more biomass available for alternative uses. Countries such as Mexico and Colombia have a low correlation between both the parameters due to the increase in the harvested hectares and reduction of their performance per hectare.

Keywords: CO_2 emissions, biomass burning, sugarcane, harvested area, cane waste

1. Introduction

The biomass burning refers to the complete or incomplete combustion of living or dead vegetation by natural or anthropogenic causes [1]. The residual burning carried out worldwide is

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emitting a great variety of pollutant species and greenhouse gases such as particulate matter (PM), nitrous oxide (N_2O), carbon monoxide (CO), methane (CH_4) and hydrocarbons [2], and so on to the atmosphere. The waste obtained from burning agricultural waste occupies the second place in the world (**Table 1**).

One of the crops that contribute to the increase in agricultural residues is sugarcane (*Saccharum officinarum*) and it is cultivated in more than 100 countries around the world [4]. Brazil has the first place in production, followed by India and China, while the United States and Mexico have the sixth and seventh place, respectively (**Figure 1**). This crop has a great economic and alimentary importance, for example, in 2011 it had a world production of about 1.7 billion tons [5], thanks to the variety of products such as sugar, piloncillo, alcohol and food for livestock, and so on. The sugar production and their resulting products depends of the good performance of the crop, which is in function of the saccharose and biomass [6].

The mechanisms of cane harvesting in most of the countries involve their burning before and after the cutting process to remove weeds and to scare animals and insects in harvest area. This crop, well developed, favors the economy and food supply, although it may also contain a great quantity of residues which emit a great quantity of pollutants and greenhouse gases to the atmosphere when burned. In addition, the soil health can be affected due to the loss of important nutrients such as carbon and nitrogen. If these nutrients do not recover, the yield production in the next harvest period can be negative [7, 8].

The sugarcane production per hectare (in t ha^{-1}) let to know the countries that more burn this crop in the world due to there is a major quantity of biomass available during the harvest period. In 2009, countries such as Brazil, Australia and the United States had a yield ranges between 65 and 88 t ha^{-1}, while in other countries such as Mexico and India had a range between 48 and 65 t ha^{-1} [9]. The biomass burning can also increase if there is an increase in available hectares to plant this crop. In Mexico, this situation occurs in its main cane harvesting regions [10, 11].

Source of burning	Burning biomass (Tg* of dry matter/year)	Released carbon (Tg* of dry matter/year)	Total proportion of released carbon
Savannas	3690	1660	42.1
Agricultural waste	2020	910	23.1
Tropical forest	1260	570	14.5
Wood for combustibles	1430	640	16.2
Temperate and boreal forests	280	130	3.3
Carbon	21	30	1.0
Total	8700	3940	100

*1 Tg = 1×10^{12} g.

Adapted from Ref. [3].

Table 1. Annual global estimate of the amount of biomass burned and carbon released to the atmosphere.

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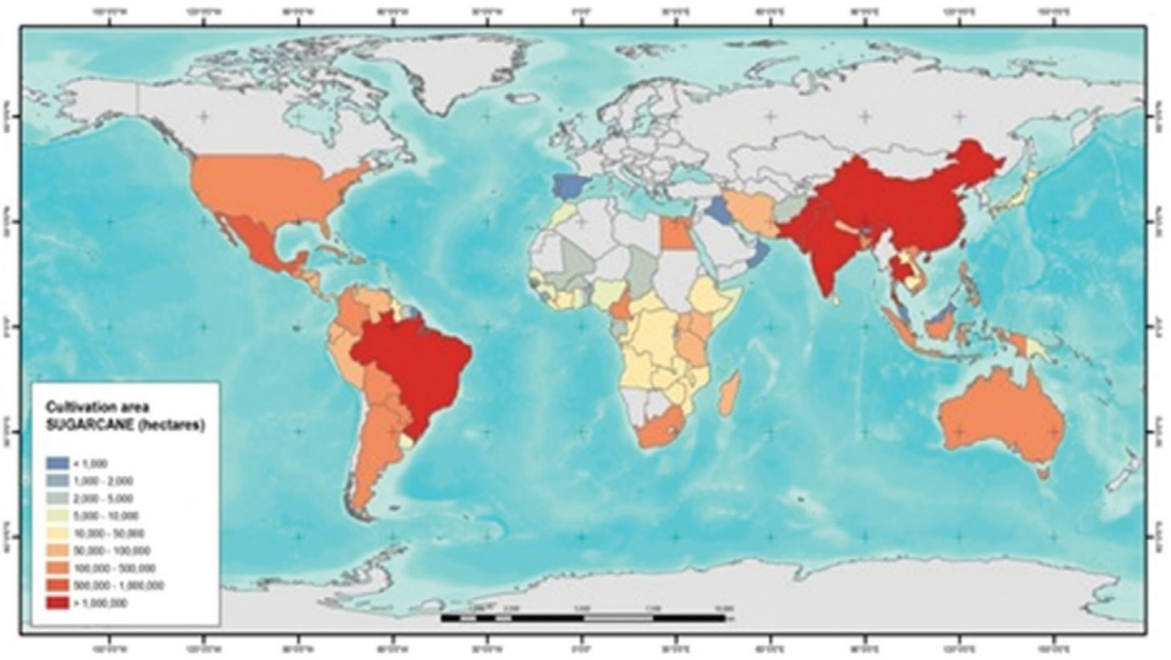


Figure 1. Cultivation area dedicated to the sugarcane production worldwide.

The quantity of biomass contained in the crop depends on their development which depends on: geographical, meteorological and edaphological factors [12], related to each other in every stage of their growth [13]; and the cane variety planted (**Table 2**). For example, the efficiency of the photosynthesis process depends on the quantity of solar radiation that affects the leaves of the plants.

The production of the sugarcane is highly correlated with the harvested area as shown in **Figure 2**. There are some countries where the correlation decreases due to diminishing yield levels. For example, in Indonesia, after 2007, while the production declined, the harvested area increased; or in Colombia, where the harvested area increased while the production kept constant. In most cases, there is a positive trend in both parameters in some countries such as Mexico, Brazil, China and India.

Country	Cane variety	Area cover (%)	Characteristics
Brazil	RB867515	26	High cane yield; excellent performance under mechanized planting and harvesting; resistant to orange rust, brown rust, smut, mosaic; tolerant to leaf, scald ratoon stunting disease (RSD).
	RB966928	10	
India	Co 0238	Not available	Subtropical adaptation; high sucrose; high cane yield; nonflowering; nonlodging; moderately resistant to red rot; resistant to smut; tolerant to drought; very good ratooning.
	Co 86,032	Not available	Tropical adaptation; high sucrose; high cane yield; shy flowering; nonlodging; moderately susceptible to red rot; resistant to smut; tolerant to drought; excellent ratooning.
China	ROC22	54.8	High sucrose; high and stable ton; poor ratoon; moderately resistant to smut; susceptible to mosaic.

Country	Cane variety	Area cover (%)	Characteristics
Thailand	KK3	53	High cane yield; high sugar; good tiller; loose leaf sheet; difficult to flower; poor ratooning if serious drought; moderately resistant to smut and red rot.
	LK92-11	31	High cane yield; high sugar content; good tiller; few stalk flower; suitable for irrigation condition; not suitable for sandy soil; resistant smut and red rot.
United States	HoCP96-540	17.6	Excellent sugar yield; excellent cane yield; moderate sugar recovery; resistant to mosaic; resistant to smut; resistant to leaf scald, susceptible to brown rust; resistant to orange rust; susceptible to sugar borer; excellent cold tolerance.
	CP 89-2143	8.6	High sugar content; moderate cane yield; resistant to brown rust; susceptible to orange rust; resistant to smut; resistant to leaf scald; moderately susceptible to mosaic; moderately resistant to RSD; susceptible to yellow leaf syndrome; no flowering.
	L99-226	7.7	Excellent sugar yield; moderate cane yield; excellent sugar recovery; resistant to mosaic; susceptible to smut; susceptible to leaf scald; susceptible to brown rust; resistant to orange rust; resistant to sugarcane borer; poor cold tolerance.
Mexico	Mex 69-290	25.4	Resistant to orange rust; brown rust; smut; leaf scald; sugarcane mosaic virus; scarce flowering; mid maturity.
	Mex 79-431	6.4	Resistant to orange rust; brown rust; smut; leaf scald; sugarcane mosaic virus; mid maturity; regular flowering.
Australia	Q208	32.3	Widely adapted, resistant to brown rust, chlorotic streak, leaf scald, mosaic orange rust, red rot, RSD, smut. Intermediate-susceptible to Fiji leaf gall.
Pakistan	HSF-240	24.3	Subtropical adaptation; tolerant to drought and frost; moderately susceptible to red rot; resistant to rust; highly susceptible to smut; resistant to ratoon stunting disease; resistant to red stripe.
	SPF-234	21.9	High yielding; moderate to high CCS; highly susceptible to red rot; susceptible to rust; resistant to smut; resistant to ratoon stunting disease; resistant to red stripe.
Colombia	CC 85-92	52	High cane yield; medium sugar yield; average self-trashing; adapted to semidry zone; resistant to orange rust, smut, mosaic, sugarcane yellow leaf virus; susceptible to brown rust, RSD, leaf scald.
Indonesia	Kenthung	Not available	Moderate germination ability; moderate stalk density; sporadically flowering; early-mid ripening variety; tolerant to top and steam borer; resistant to leaf scald, pokkah boeng, smut and mosaic; suitable for nonirrigated areas and regosol soil type with sufficient water resources.
Philippines	VMC84-524	16	Intermediate to yellow spot; highly resistant to ring spot; very highly resistant to red rot of the midrib; moderately resistant to red rot of the leaf sheet; slight infestation of thrips; high tillering, fast growing, heavy trichomes.
	VMC86-550	11	Susceptible to smot; susceptible to Downy Mildew; highly resistant to yellow spot; very highly susceptible to yellow leaf syndrome especially in the edge of field and waterlogged areas; highly resistant to rust; susceptible to borer.
	PHIL80-13	10	Rated as sweet cane; low to medium tillering; versatile in varied soil and weather types; nontasselling.

Table 2. Top varieties of sugarcane that cover between 30 and 50% of the area dedicated to this crop for major sugarcane producing countries.

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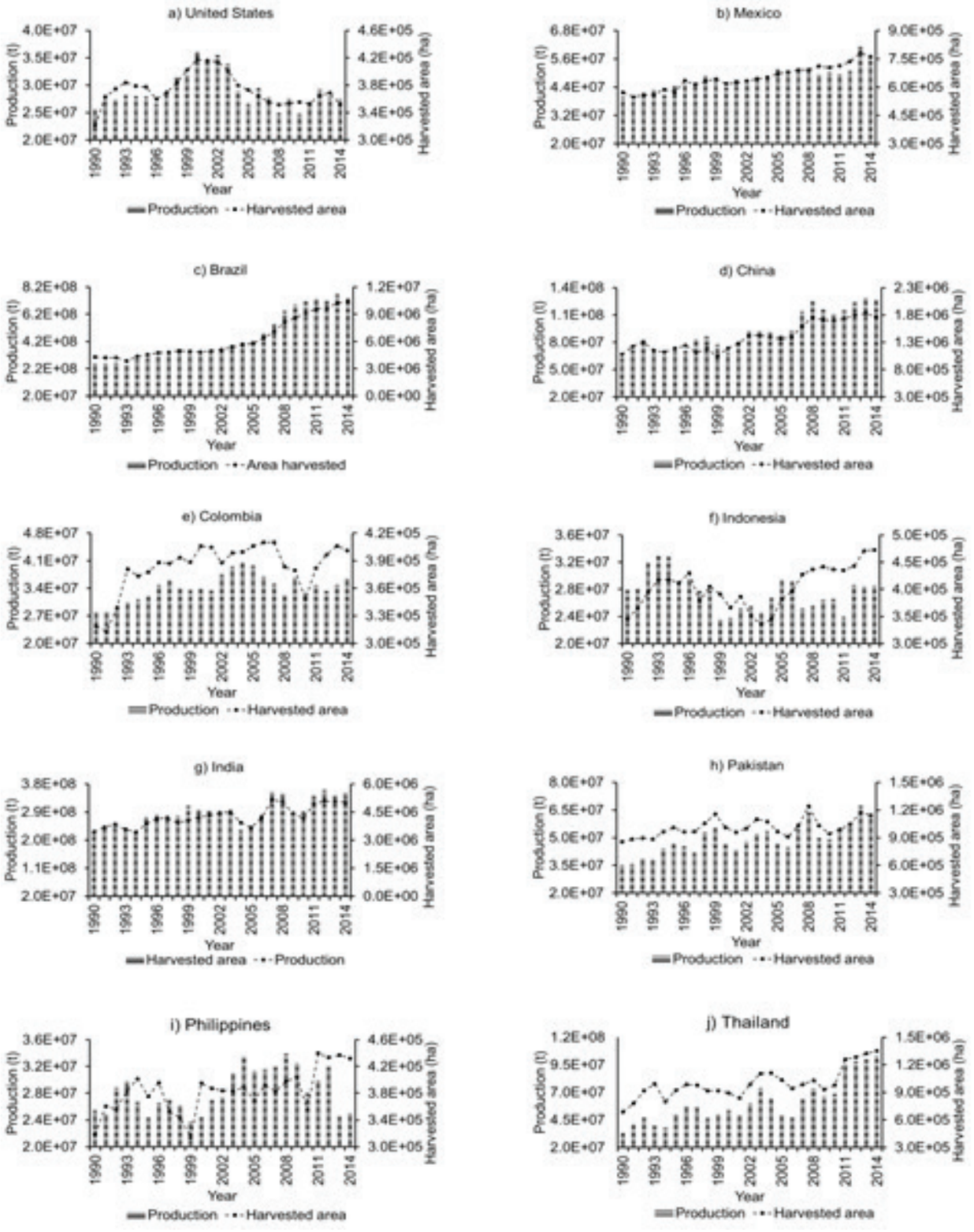


Figure 2. Annual production and harvested area for the period 1990–2014 in the principal sugarcane producers worldwide. United States (a), Mexico (b), Brazil (c), China (d), Colombia (e), Indonesia (f), India (g), Pakistan (h), Philippines (i) and Thailand (j). The data used to realize the charts were obtained from FAOSTAT [14].

The high- or low-correlation between the harvested area and sugarcane production can be an indicator of the good or bad treatment received by the soil in every planting period, depending on the infrastructure available to keep the soils healthy in each country.

The sugarcane varieties used in the countries dedicated to the production of this crop have special qualities to respond efficiently to the soil and weather characteristics of every place and have important properties of sucrose and biomass availability (**Table 2**). The International Society of Sugarcane Technologists collects and periodically publishes the most recent varieties of cane in each country dedicated to the sugarcane production.

The maturation period of these cane varieties is another important characteristic, which is taken into account in the moment to decide the harvesting period and the quantity of residue available to be burned. The two cane varieties of Brazil showed in **Table 2** [15] have the medium to late maturation (first variety) and early maturation (second variety), respectively; for China's varieties correspond to early maturation.

2. CO_2 emissions during the harvest of sugarcane in the major sugarcane producing countries

The database used to obtain and analyze the CO_2 emissions for the period 1990–2014 was acquired from FAOSTAT – Burning Crop Residues [16], whose empiric calculus depend of the Tier 1 methodology proposed by the Intergovernmental Panel on Climate Change. The main characteristics of these levels are the use of the basic information of every country, necessary to know a first estimation of the emissions of this greenhouse gas [17].

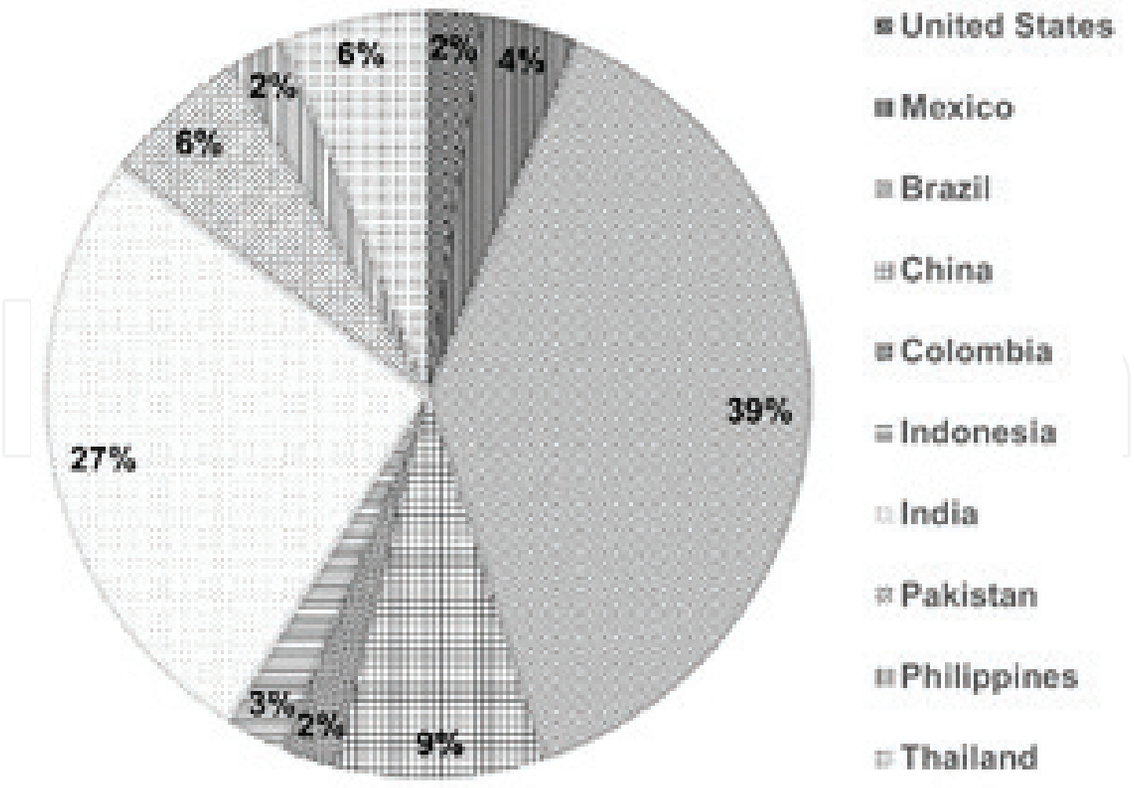


Figure 3. Total biomass burned during sugarcane harvest (dry matter).

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The country with the major surface area dedicated to the sugarcane production is Brazil. Their total CO_2 emissions are generated in harvested areas by burning and green harvesting. In both cases, this greenhouse gas is emitted [18]. When sugarcane is burned, its variety planted plays an important role in the quantity of biomass available to be burned (**Figure 3**).

The average dry matter in the sugarcane ranks between 22.7 and 35.9% [19]. However, depending on the variety of sugarcane planted, it will have the real quantity of residue. For example, in Mexico, the main planted varieties have a residual fraction of 29%, from which 83% is dry matter [20].

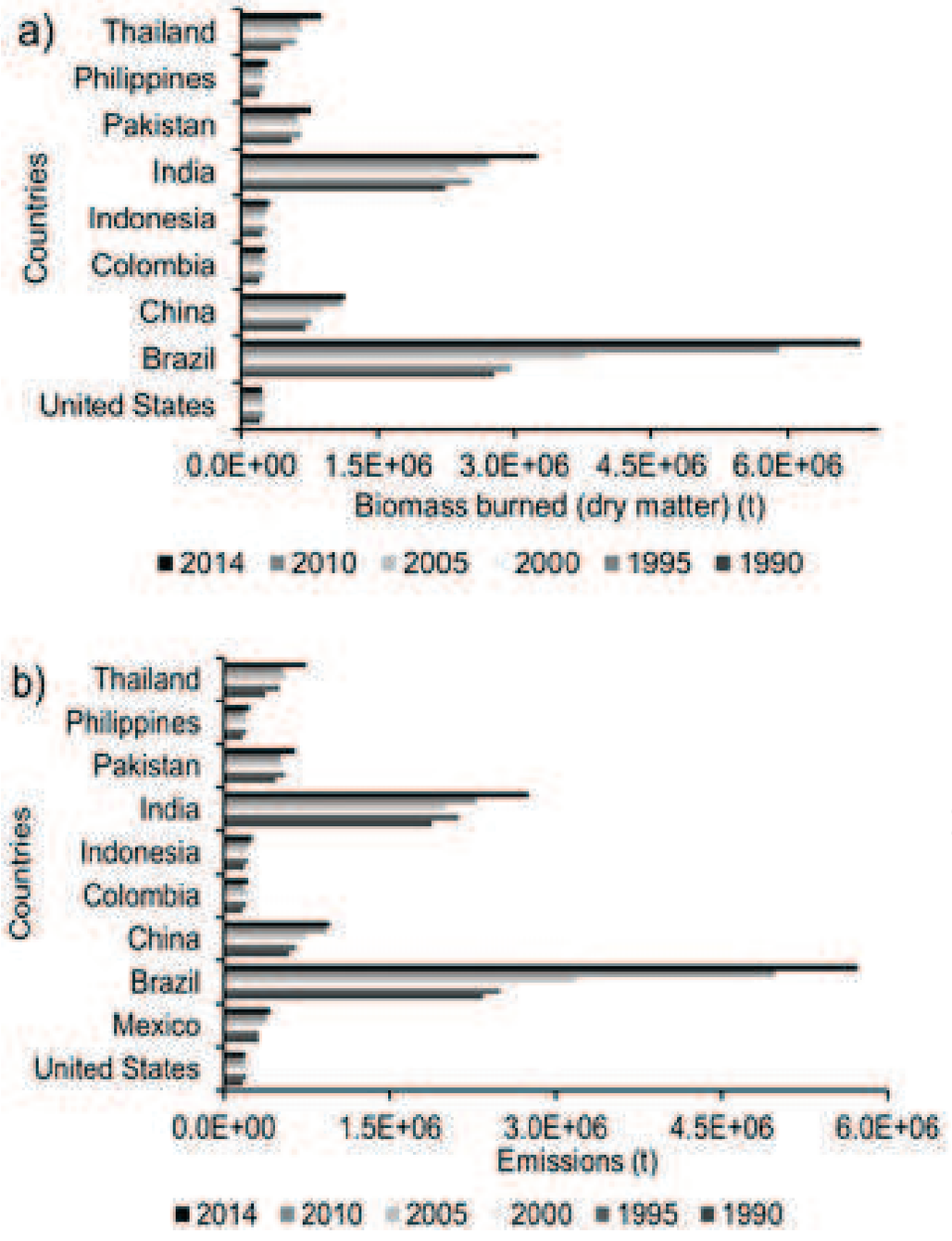


Figure 4. Biomass burned (dry matter) (a) and CO_2 emissions (b) by the major sugarcane producing countries.

There is a correlation between the biomass burned (**Figure 4a**) and CO_2 emissions (**Figure 4b**). Brazil, India and China have the highest level of both parameters. Their magnitude order is of millions of tons, and the magnitude order of sugarcane production by country (**Figure 2**) is higher than biomass burned because the dry matter is a percentage of the crop. In every year of the study period (1990–2014), the cane production, biomass burned and emissions of CO_2 have been increasing, not only by alimentary reasons but also by energetic needs reflected in the use of biomass to generate electric energy and the implementation of ethanol and its derivatives as fuels.

Actually there is no particular database in which the available nutrients for every planted period of sugarcane can be found. However, there exists general information that can help to understand the global distribution of soils and nutrients [21]. This information is important due to the volatilization of nutrients during the burning practice in every harvested period. The IPCC's methodologies estimate the greenhouse gas emissions, although other proposals, for example, the Seiler and Crutzen methodology [22], are very useful to know the amount of carbon and nitrogen released to the atmosphere during the burning of some crops.

A particular way to identify the conditions in which the sugarcane plantation was carried out is by referencing the values proposed to identify the "aptitude levels of sugarcane." It consists of identifying the soil and weather conditions in which the sugarcane cultivation takes place [23] and relates with the production per hectare (yield).

According to this methodology implemented for the sugarcane producing regions in Mexico during the period of 1990–2014, the yield per hectare ranked between 81.3 and 92.3 t ha^{-1} [25]. This shows a high aptitude level for the country. It is not possible to use the same values from **Table 3** for other sugarcane cultivating countries because the edaphological and weather conditions are different.

Property	High	Medium	Low	Not suitable
Annual temperature (°C)	22–32	20/22–32/35	18–20	<18
Annual average precipitation (mm)	>1500	1250–1500	1250–1000	<1000
Solar radiation (h/year)	1800–2200	1800–1400	1400–1200	<1200
Drought severity index	Absent	Slight	Strong to very strong	Severe
Slope (%)	0–8	8–16	16–30	>30
Altitude (masl)	Up to 400	400–850	850–1300	>1300
Texture	Loam-Argillaceus	Argillaceus	Loam-sandy	Sandy
pH	6.6–7.3	6.1–6.5, 7.4–8.3	5.6–6-0 > 8.3	<5.5
Organic matter (%)	>5	3–5	2–3	1–2
Available nitrogen (kg/ha)	>300	300–225	225–150	<150
C/N relation	8–12	12–15	15–30	>30
Expected yield (t ha^{-1})	>80	55–80	40–55	<40

Table 3. Aptitude levels of sugarcane. Proposed values for Mexico [24].

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3. Competitive use of the sugarcane waste

The sugarcane harvest can be done with or without burn. However, the ways to use the residues depend on the kind of processes involved during the cane lifting [26]. In general, the crop residues can be used as animal feeding and for energy generation. It is also used as a raw material for the production of honey, yeast, alcohol, hydrolyzed products, paper and fertilizers (**Figure 5**) [27].

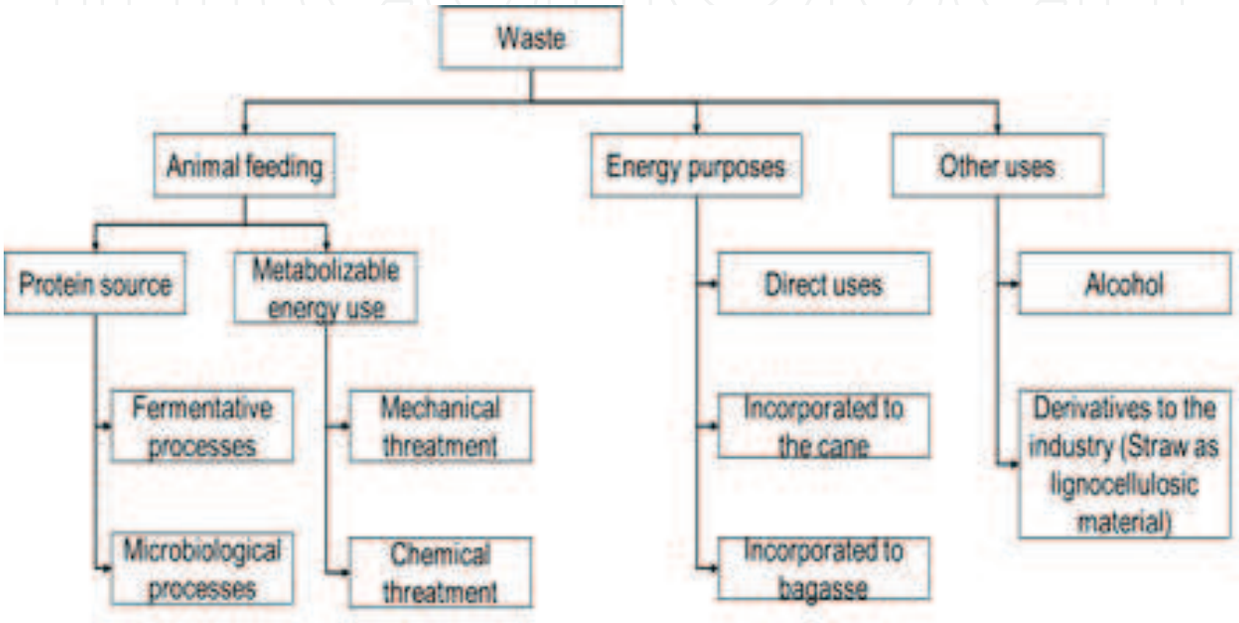


Figure 5. Uses of sugarcane straw [29].

Country	Pearson correlation
United States	0.54
Mexico	0.042
Brazil	0.74
China	0.40
Colombia	0.09
Indonesia	−0.63
India	0.28
Pakistan	0.62
Philippines	0.44
Thailand	0.71

Table 4. Correlation between the harvested area and yield per hectare during the period 1990–2014.

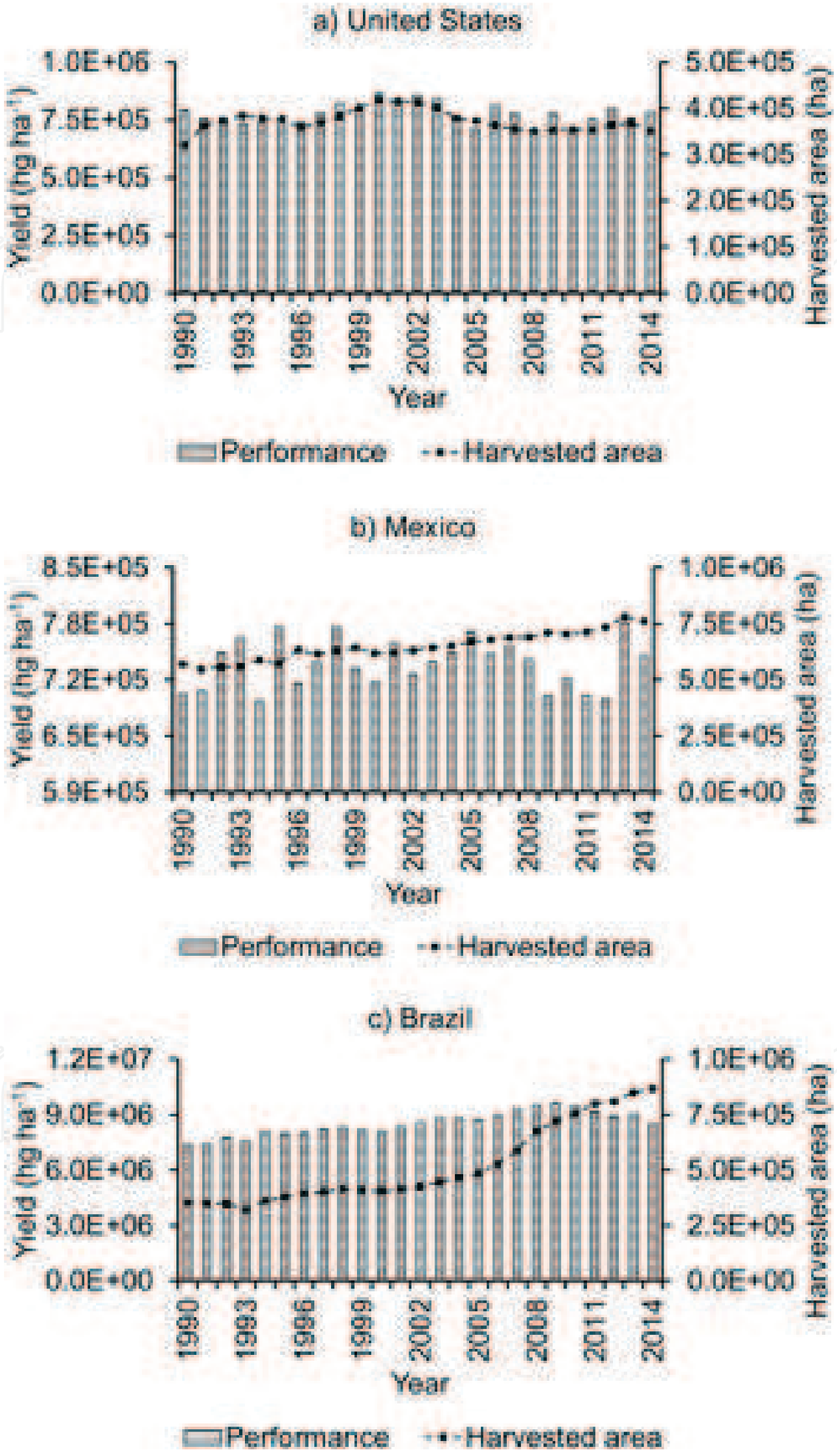


Figure 6. Relation between yield per hectare and harvested hectares in the United States (a), Mexico (b) and Brazil (c). 1 hg = 0.0001 t.

Actually, 85% of the world production of liquid biofuels corresponds to ethanol, where the main producers are Brazil and the United States because they contribute to 90% of their world production. The other 10% corresponds to Canada, China, European Union (France and Germany) and India (**Table 4**). The sugarcane plays an important role in the production of this fuel through fermentation and distillation processes [28].

The results shown above can be indicators of the capability of every country to take advantage of the crop residues to use it in an alternative manner. The Pearson correlation analysis between the harvested area and yield per hectare during the period 1900–2014 (**Table 4**) shows that countries such as Brazil and the United States have a better use of the planted soils, but for different reasons. For example, Brazil had a positive trend in both parameters during the studied years (**Figure 6c**), while the United States has increased the harvested hectares while keeping practically a constant yield per hectare.

Mexico had a positive trend in the harvested area, at a much higher level than the United States (**Figure 6a** and **b**) or the Philippines. However, the performance per hectare is constant but at lower levels than United States. This situation reveals that countries such as Mexico, Colombia and India have to invest more resources to keep their production levels constant and to generate useable residues for alternative uses.

The generation of waste from this crop in the sugarcane producing countries depends primarily on the performance of sugarcane production. In this context, the major biofuel (ethanol and biodiesel) producing countries are Brazil, the United States, China and India [30].

4. Conclusions

The biomass (dry matter) available to be burned during the harvest period of sugarcane, play an important role in the CO_2 emission levels generated by the countries that practice this activity, and its release into the atmosphere can increase or decrease due to other factors such as soil quality, cane varieties used and weather conditions.

In this chapter, we can see the important relation between the production levels and harvested areas, an extensive harvest surface not necessarily give high production levels. Countries such as Colombia, Indonesia and Philippines had this behavior in their planted soils in different years. On the other hand, Brazil, China, India, Mexico, the United States, Pakistan and Thailand had a good correlation between both the parameters because when the harvested hectares increased or decreased, the production levels remain the same.

During the study period (1990–2014), we can see that Brazil, India and China had the highest quantity of cane waste (dry matter) burned and simultaneously had the better production levels and the major emissions of $CO_{2.}$ In general, the countries analyzed had a positive trend reflected in the annual increase of its emissions, except for the United States which reduced its production levels since 2004.

The countries that kept a good correlation between their yield levels and harvested area during the study period, it is because they have had the infrastructure to prepare their soils adequately and use the cane varieties that can be adapted to each condition presented in every

stage of growth in the best way, but also have major possibilities to take advantage of the available cane waste and give it an alternative use.

Finally, to reduce CO_2 emissions, it is not necessary to reduce the production levels, rather, good performance must be maintained using appropriate planting and harvesting techniques which also allow the waste (dry matter) to be disposed of in suitable conditions to be used. Actually, it could be expensive to implement these alternative practices, so every country must generate a new mechanism to make it more feasible.

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References

[1] Levine JS. Biomass burning: The cycling of gases and particulates from the biosphere to the atmosphere. In: Keeling RF, editor. Holland HD, Turekian KK, Executive editors. Treatise on Geochemistry. Vol. 4. Elsiever. 2003. pp. 143-158. https://doi.org/10.1016/B0-08-043751-6/04143-8

[2] Hao WM, Ward DE. Methane production from global biomass burning. Journal of Geophysical Research. 1993;**11**:20,657-20,661

[3] Andreae MO. Atmosphere climatic and biospheric implications. In: Levine JSE, editor. Global Biomass Burning. Cambridge, MA: MIT Press; 1991

[4] Pérez R. Sugar cane. In: Feeding Pigs in the Tropics. Produced by Agriculture and Consume Protection. AGAP; 2015. Available from: http://www.fao.org/livestock/AGAP/frg/APH132/chap3.htm Accessed: July 12, 2017

[5] FAO. Statistical Yearbook. World Food and Agriculture [Internet]. Rome; 2013. Available from: http://www.fao.org/docrep/018/i3107e/i3107e.PDF Accessed: July 23, 2017

[6] Aguilar-Rivera N. Ficha técnica del cultivo de Caña de Azúcar. San Luis Potosí, México; 2013. Available from: http://nutriciondebovinos.com.ar/MD_upload/nutriciondebovinos_com_ar/Archivos/File/CA%C3%91A_DE_AZ%C3%9ACAR,_FICHA_T%C3%89CNICA.pdf Accessed: July 15, 2017

[7] Chen L-WA, Verburg P, Shackelford A, Zhu D, Susfalk R, Chow JC, Watson JG. Moisture effects on carbon and nitrogen emission from burning of wildland biomass. Atmospheric Chemistry and Physics Discussions. 2010;**10**:7985-8007

[8] França D de A, Longo KM, Soares NTG, Santos JC, Freitas SR, Rudorff BFT, Cortez EV, Anselmo E, Carvalho A Jr. Pre-harvest sugarcane burning: Determination of emission factors through laboratory measurements. Atmosphere. 2012;**3**:164-180

[9] FAOSTAT. Production Statistics [Internet]. 2009. Available from: http://faostat3.fao.org/browse/Q/*/E [Accessed: April 11, 2017]

[10] Flores-Jiménez DE, Algara-Siller M, Aguilar-Rivera N, Carbajal N, Aldama-Aguilera C, Ávila-Galarza A, Álvarez-Fuentes G. Influence of sugarcane burning on soil carbón and nitrogen reléase under drought and evapotranspiration conditions in a Mexican sugarcane supply zone. Revista Internacional de Contaminación Ambiental. 2016;**32**:177-189

[11] Flores-Jiménez DE, Algara-Siller M, Aguilar-Rivera N, Aldama-Aguilera C. Chapter 3: Methane emissions and productivity index in the Mexican sugarcane crop fields. In: Murphy R, editor. Sugarcane. Production Systems, Uses and Economic Importance. New York: NOVA Publishers; 2017. p. 73-104

[12] Haynes RJ. The concept of soil quality and its applicability to sugarcane production. Proceedings of the Annual Congress-South African Sugar Technologists Association. 1997;**71**:9-14

[13] Epiphanio JCN, Gleriani JM, Formaggio AR, Rudorff BF. Theodor: Índices de vegetação no sensoriamento remoto da cultura do feijão. Pesquisa Agropecuária Brasileira, Brasília. 1996;**31**:445-454

[14] FAOSTAT. Food and Agriculture Data. 2017. Available from: http://www.fao.org/faostat/en/#home [Accessed: July 15, 2017]

[15] ISSCT. Sugarcane Varieties. International Society of Sugarcane Technologists. 2014. Available from: http://sugarcanevariety.org/Default.aspx [Accessed: August 20, 2017]

[16] FAOSTAT. Burning-Crop Residues. 2017. Available from: http://www.fao.org/faostat/en/#data/GB [Accessed: August 14, 2017]

[17] IPCC. Agriculture, forestry and other land use. In: IPCC Guidelines for National Greenhouse Inventories. Vol. 4. 2006. Available from: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html Accessed: August 10, 2017

[18] Moraes Tavares RL, Menezes de Sousa Z, Silva SD, La Scala JN, Panosso AR, CMC C. Soil CO_2 emission in sugarcane management systems. In: Acta Agriculturae Scandinavica, Section B – Soil & Plant Science. United Kingdom of Great Britain & Northern Ireland: Taylor & Francis; 2015

[19] Lam E, Carrer H, da Silva JA, Kole C. Chapter 2: The agronomy of switchgrass for biomass. In: Chittaranjan Kole, editor. Compendium of Bioenergy Plants. CRC Press. Taylor & Francis Group. 2014. p. 17-66

[20] Ordóñez DJA, Hernández TT. Obtención de Factores de Emisión en el Sector Agrícola para disminuir incertidumbre en el Inventario Nacional de Emisiones de Efecto Invernadero. México: Instituto Nacional de Ecología y Cambio Climático. Report; 2006

[21] GAEZ. Global Agro-Ecological Zones. 2017. Available from: http://www.fao.org/nr/gaez/acerca-del-portal-de-datos/es/

[22] Levine JS. Biomass burning: The cycling of gases and particulates from the biosphere to the atmosphere. Treatise on Geochemistry. 2003;**4**:143-158

[23] Sánchez-Hernández R, Ramos-Reyes R, Geissen V, Mendoza-Palacios J de D, de la Cruz Lázaro E, Salcedo PE, Palma-López D. Contenido de carbonos en suelo con diferentes usos agropecuarios en el trópico mexicano. Terra Latinoamericana. 2011;**29**:211-219

[24] Aguilar-Rivera N, Olvera VA, Galindo MG. Evaluación de aptitud de tierras de cultivo de caña de azúcar en la Huasteca Potosina, México por técnicas geomáticas. Revista de Geografía Norte Grande. 2013;**55**:141-156

[25] SIAP. 2016. Anuario Estadístico de la Producción Agrícola. Available from: http://www.fao.org/nr/gaez/acerca-del-portal-de-datos/es/

[26] SAGARPA. Aprovechamiento de residuos de la caña de azúcar. México: Nota Técnica Informativa del sector de la caña de azúcar; 2016

[27] Basanta R, García Delgado MA, Cervantes Martínez JE, Mata VH, Bustos VG. Sostenibilidad del reciclaje de residuos de la agroindustria azucarera: una revisión. Ciencia y Tecnologia Alimentaria. 2007;**5**:293-305

[28] FAO. Parte 1. Biocombustibles: Perspectivas, riesgos y oportunidades. In: FAO, editor. El estado mundial de la agricultura y la alimentación. Roma: p. 11. 2008. ISBN: 978-92-5-305980-5

[29] León- Martínez TS, Dolpíco-Ramírez D, Triana-Hernández O, Medina-Estevez M. Paja de la caña de azúcar. Sus usos en la actualidad. ICIDCA. Sobre los Derivados de la Caña de Azúcar. 2013;**24**:13-22

[30] Licht FO. Licht Interactive Database (Available by Subscription). 2007. Available from: https://store.agra-net.com/licht-interactive-database-sugar.html [Accessed: June 12, 2017]