International Journal of Agricultural Technology 2017 Vol. 13(2):247-267
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

No Burning Sugarcane Trashes Makes Sugarcane Production - Net Carbon Sequestering

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Mendoza, T. C. (2017). No burning sugarcane trashes makes sugarcane production - net carbon sequestering. International Journal of Agricultural Technology 13(2):247-267.

Abstract The No cane burning/trash farming practice could shift sugarcane production from carbon emitting into carbon sequestering (carbon negative) due to the following: 1) direct C-sequestration from humus-C incorporated in the soil at 6.0 t CO_2e/ha ; 2) avoidance of emission of CH_4, CO, N_2O during cane burning at 1.794 t CO_2e/ha ; 3) Increased the ratoon cycles from the usual one to two ratoons to 4 up to 6 ratoons leads to avoided carbon dioxide emission at 0.257 t CO_2e/ha/ratoon ; 4) the conserved three macronutrients (N, P, K) at 0.814. t CO_2e/ha ; 5)the avoided emission due to N-fixation in the decomposing trash that reduces the nitrogen fertilizer input to be applied to grow sugarcane at 3.09 t CO_2e/ha; or a total of 11.955 t CO_2e/ha . The calculated carbon emission in the usual sugarcane production practice centered on burning canes was 7.591 t CO_2e/ha .The ex –ante carbon balance of no burning /trash farming is 4.364 t CO_2e/ha . The challenge is how to STOP burning of canes before and after harvest. An agro-environmental Protocol must be formulated and be agreed upon by the planters association and the government for implementation in the different sugarcane producing provinces.

Keywords: No cane burning, trash farming, carbon sequestration, ex-ante carbon balance, Nitrogen fixation, sugarcane

Introduction

Sugar production from sugarcane directly and indirectly contributes significant amount of greenhouse gases (CO_2, CH_4, N_2O, CO) in the atmosphere. The direct contribution comes from burning fossil fuel oil by the machinery requiring operations starting from land preparation, cultivation, harvesting and hauling canes to the mill. In addition, bunker oil is also needed to start the sugar mill and from thereon, bagasse, a by-product after extracting the juice from the sugarcane stalks is used as fuel (Corpuz and Aguilar,1992). The indirect contribution comes from the various inputs which include the manufacture of fertilizers, and pesticides using oil or natural gas, oil energy that is used by the ships, and trucks to transport the fertilizer and pesticide from the

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site of manufacturer to the sugarcane fields. In addition, an indirect emission called the embedded emission of machine manufacture (tractors, farm implements, sugar mills and parts) and the buildings or warehouses for sugar storage. Add to these are the indirect emissions due to the human labor employed from crop establishment, crop care, harvesting, hauling, and milling and others (Mendoza and Samson, 2004).

In earlier studies (Mendoza and Samson, 2000; Mendoza 2014; and Mendoza *et al*., 2015), the largest GHG-CO_2 emission comes from fertilizer input, particularly nitrogen. The Haber-Bosch process of manufacturing nitrogen fertilizer requires high temperature and pressures where oil and natural gas are the main source of fossil fuel energy-based emission(Clark 2009).

Minimizing GHG-CO_2 emission sugar production from sugarcane (a crop species that fixed CO_2 via the C_4 – pathway of CO_2 fixation) is a huge challenge. In this study, a carbon emission audit of various operations, inputs and farm practices in sugarcane production from crop establishment, crop care, harvesting and hauling canes to the mill was done. Specifically, the study aimed to determine the carbon emission hotspots in the various stages of the field level sugarcane production and based from the current GHG – CO_2 emission audit , a production systems – change, including policy imperatives were recommended.

Materials and methods

Source of Data for calculations

The primary field survey data of Mendoza and Samson (2004) were updated (Mendoza, 2016) through key informants' interview which included leaders of sugarcane planters association in Batangas and Negros Occidental, Philippines. The data were used in calculating the carbon emission from farm operations following established procedures (Lal, 2004).

The calculation of Ex-ante Carbon balance

The Ex-ante carbon balance is an estimate of the difference between the C-emission and the sequestered C-below and above ground (Bernoux *et al*. 2010a; 2010b). Applied in sugarcane production, C-emission comes from cane burning (pre-or post-harvest), or the *practice-as-usual* scenario while attributed the C-sequestered comes from the non-burning set of practices but only few sugarcane planters in the Philippines are doing it. The ex-ante calculation of carbon balance is described below.

$$CB_{ex-a} = \sum\left(CE_{w/b}\right) - \sum\left(CE_{w/ob}\right);\qquad \text{Eqn.1}$$

Where: CB_{ex-a} *= ex-ante calculated carbon balance which is the difference between the calculated total carbon dioxide emission with burning or the practice-as-usual* scenario *and No burning of sugarcane either before or after harvest,* $\sum\left(CE_{w/b}\right)$ *= ex-ante calculated total sequestered and avoided carbon emission without cane burning as estimated in Eqn.2.* $\sum\left(CE_{w/ob}\right) = \sum\left(CS_{r.s.t}\right) + \sum\left(AE_{n+ns}\right)$ *Where:* $\sum\left(CS_{r.s.t.}\right)$ *= sum of calculated carbon sequestered in the roots, stubbles, and unburnt trash ;* $\sum\left(AE_{n+ns}\right)$ *= sum of avoided emission of the unburnt nutrients/ nitrogen phosphorus, and potassium plus the nitrogen fixed during trash decomposition at 10 kg N fixed per ton of trash (Patriquin, 2000).*

The carbon dioxide emission or carbon footprint for sugarcane production had been done earlier by Mendoza (2014); Mendoza *et al*. (2015; Demafelis *et al*. (2015). And they were adopted in the current study. Briefly, the procedure adopted was to calculate the carbon dioxide emission from crop establishment, crop care and management, farm inputs, particularly fertilizers, harvesting and hauling, and embedded energy of the tractors and trucks for the 2 crop types –plant cane and ratoon cane. The carbon dioxide emissions attributed to the various operations and inputs used in sugarcane production were estimated using the formula:

$$\sum \mathrm{CO2e} = \sum\left(\mathrm{CE_{CO2e}} + \mathrm{CM_{CO2e}} + \mathrm{F.I_{CO2e}} + \mathrm{HH_{CO2e}} + \mathrm{E_{CO2e}}\right)\qquad \text{(Eqn.3)}$$

Where: $\sum \mathrm{CO2e}$ *= sum of the* CO_2e *of sugarcane production;*$C.E_{CO2e}$ *= total* CO_2e *of crop establishment ;*$C.M_{CO2e}$ *= total* CO_2e *of caring and managing the crop ;*$F.I_{CO2e}$ *= total* CO_2e *of farm inputs (fertilizer and herbicides) ;*$H.H_{CO2e}$ *= total* CO_2e *of harvesting and hauling;* E_{CO2e}*/ha = embedded* CO_2e *of tractors and hauling trucks .* The detailed calculations were described in Mendoza (2016) and the details are described in the section below (calculating the carbon footprint of sugarcane production).

Burning canes is the *practice-as usual o*f the sugarcane planters in the Philippines .The procedure for estimating carbon dioxide emission equivalent (CO_{2e} equiv.) from burning canes formulated by Mendoza (2014) and Mendoza and Demafelis *et al*. (2015) was adopted. It is shown in the equation…..

$$\mathrm{CO_2e\ equiv} = \sum\left(\mathrm{CH_{4e}xCO_{2ec}}\right) + \left(\mathrm{CO_e xCO_{ec}}\right) + \left(\mathrm{N_2O_e xCO_{2e}}\right)$$

(Eqn.4.) *Where:* CO_2e *equiv =total carbon dioxide equivalent of methane (*CH_4*), carbon monoxide (CO), and nitrous oxide (*NO_x*) emission;* CH_{4e} *=methane emission during burning multiplied by 28 the global warming* CH_4 *relative to* CO_2 *;* N_2O_e *=carbon dioxide emission equivalent of nitrous oxide emission on burning multiplied by 298, the global warming potential of* N_2O *relative to* CO_2*.*

No burning of canes and the practice of trash farming lead to avoided emission of carbon dioxide. The formula used in calculating avoided emission of carbon dioxide is shown below:

$$AeCO_e = \sum\left(HC_s + Ae_{ghge} + Ae_{Nf} + Ae_{nu} + Ae_{RC5}\right) \quad \text{(Eqn.5)}$$

Where: $AeCO_{2e}$ = sum of the CO_{2e} avoided emissions ;HC_s = non-emitted CO_2 as the organic matter decompose and becomes stable humus-C ;Ae_{ghge}= avoided emission of methane, carbon monoxide and nitrous oxide due to non-burning (adopted from Mendoza 2014);Ae_{nf}= avoided emission due to nitrogen fixation at 10 kg N/ton of trash unburnt (Patriquin, 2000); Ae_{nu} = avoided emission due to unburnt nutrients, were given CO_2e per kg; Ae_{RC5}= avoided emission due to more ratoon (5 ratoon cycle)

Calculating the Carbon Footprint of Sugarcane Production

The carbon dioxide emissions attributed to the various operations and inputs used in establishing the plant cane and ratoon canes were obtained by multiplying the energy bill expressed in LDOE/ha to the carbon emission attributed to 1 liter of oil (Mendoza and Denmafeliz *et al*. 2015) using the formula ..CO_2e = $LDOE_{opr}$ x CO_2e/LDOE (Eqn. 1); Where: CO_2e =carbon emission equivalent of a particular operation i.e. plowing, harvesting, and furrowing; $LDOE_{opr}$ =energy bill of particular operation expressed into liter diesel oil equivalent (LDOE); CO_2e/LDOE = the carbon emission of 1 li oil = 3.96 kg CO_2e

The carbon emission equivalent (CO_2e) for particular operation in taking *care and managing the sugarcane crop* followed same procedure as in the crop establishment. For *farm inputs (fertilizers, pesticides),*the carbon emission equivalent varied. Direct multiplication of the equivalent CO_2e particularly for nitrogen could not be done. The energy used to manufacture, store, haul, and transport 1 kg nitrogen is known. Once applied in the field, significant amount of nitrous oxides is leached and volatilized into nitrous oxides (NO_x). The global warming potential of NO_x is 298x relative to CO_2. Hence, the estimated amount by Mendoza (2016) was adopted at 12.914 kg CO2e/Kg N. F*or harvesting and hauling*. Calculating the carbon dioxide emission equivalent was done as follows: The energy bill of cutting and loading canes to the hauling trucks that transport the cane stalks to the sugar mills was used ; CO_2e eq = LDOE x CO_2e eq/ LDOE .The same method was adopted for hauling canes to the mill. The calculated LDOE per ton cane (TC) or the equivalent energy used for one (1) hectare was used .The formula used in calculating the carbon emission in harvesting and hauling canes to the mill was

$$CO_{2eh\&h} = \sum CO_{2ecL} + CO_{2eC+B} + CO_{2ehm} \quad \text{(Eqn.2.)}$$

Where: CO_2e h and h = carbon dioxide emission in harvesting and hauling canes to the sugar mills in kg CO_2e/TC;CO_2e cl = carbon dioxide emission in cutting and loading canes to the mill in kg CO_2e/TC;CO_2e c+b = carbon dioxide emission of CH_4, CO and N_2O upon cane trash burning in kg CO_2e equivalent per TC; CO_2e hm =carbon dioxide emission equivalent in hauling canes to the sugar mills, in kg CO_2e per TC.

Cane stalks are initially loaded in small truck, then *trans* loaded into bigger trucks for hauling in the sugar mill, 100 to 120 km away.
Photo taken by: TC Mendoza

To date, burning canes (before or after harvesting to facilitate operations in ratoon cane establishment) is the dominant practice. Still, only very few planters practice trash incorporation or trash farming. Burning canes release CO_2 in the atmosphere. But it enters the biotic CO_2 cycle or the plant – atmosphere - CO_2 cycle as CO_2 is re-absorbed back in the next crop photosynthesis. Sugarcane trash contains 0.41 carbon on a dry weight basis. In the field, about 65% of all trash is burnt (Mendoza and Samson, 2004). The average trash is about 12–15% of tonnage (TC/ha). The yield data adopted was 86.25 TC ha (the farms in Eastern Batangas and N. Negros Occidental). Burning crop residues has indirect effect which is the reduction of soil organic matter which in turn, led to high application of fertilizer particularly nitrogen. This indirectly increases carbon footprint for fertilizer. The roots and stubbles summed up to about 1.7 tons/ha (Rosario and Mendoza, 1977). About 5 tons of unburnt stubbles or about 2.05 organic carbon is left in the field per ha. What remains after delisting the direct CO_2 release from burning are the 3 compounds – nitrous oxide (NO_x), carbon monoxide (CO), and methane that are released upon burning the trash. The estimation procedure formulated earlier by Mendoza (2014) and Mendoza and Demafelis *et al*. (2015) was adopted.

The net carbon dioxide emission equivalent (CO_{2e} equiv.) from burning canes is shown in the equation … CO_2e equiv = $\sum(CH_{4e} x CO_{2ec}) + (CO_e x CO_{ec}) + (N_2O_e x CO_{2e})$ Where: CO_2e equiv =total carbon dioxide equivalent of methane (CH_4), carbon monoxide (CO), and nitrous oxide (NO_x) emission; CH_{4e} =methane emission during burning multiplied by 28 the global warming CH_4 relative to CO_2 ; N_2O_e =carbon dioxide emission equivalent of nitrous oxide emission on burning multiplied by 298, the global warming potential of N_2O relative to CO_2.

Calculating avoided emission of carbon dioxide a

No burning of canes and the practice of trash farming lead to: Humus-C sequestered CO_2e; avoided emission of CH_4 CO, N_2O; avoided emission due to N-fixation; and avoided emission due to more ratoons. The formula used in calculating avoided emission of carbon dioxide is shown below:

$$AeCO_e = \sum\left(HC_s + Ae_{ghge} + Ae_{Nf} + Ae_{nu} + Ae_{RC5}\right)$$

Where: $AeCO_{2e}$ = sum of the CO_{2e} avoided emissions ;HC_s = non-emitted CO_2 as the organic matter decompose and becomes stable humus-C ;Ae_{ghge}= avoided emission of methane, carbon monoxide and nitrous oxide due to non-burning (adopted from Mendoza 2014);Ae_{nf}= avoided emission due to nitrogen fixation at 10 kg N/ton of trash unburnt (Patriquin, 2000); Ae_{nu} = avoided emission due to unburnt nutrients, were given CO_2e per kg; Ae_{RC5}= avoided emission due to more ratoon (5 ratoon cycle)

Results and Discussion

The carbon footprint of sugarcane production

Higher CO_2emission equivalent (40% more) was computed in the plant cane at 981.27 CO_2e equivalent/ha than in ratoon cane at 5201.55 kg CO_2e. Ratoon canes have lower carbon footprint at 13.03 kg CO2e per TC, 6.50 kg CO2e per Lkg and 0.13 kg CO2e per kg sugar. The reasons are: a) ratoon canes had lower yields, lower harvesting and hauling emissions; b) lower emissions in ratoon establishment than plant cane, c) lower fertilizer application due to expected lower yields (Table 1).

Table 1. The Carbon footprint of various operations in sugarcane production for *Plant Cane* and *Ratoon Cane* (Batangas and N.Negros Occ.)

Carbon dioxide Emission Source	Kg	CO_2e	% of
	per Ha	per TC	Total
PLANT CANE			
A.CROP ESTABLISHMENT	950.35	9.50	9.52
1.Land preparation*	569.96	5.70	5.71
2. Preparation and Planting	341.40	3.41	3.42
B.CARE AND MANAGEMENT	256.31	2.56	2.57
C.FARM INPUTS	2318.93	23.19	23.23
N (NOx)CO2e	1016.40	10.16	10.18
D.HARVESTING and Hauling	1065.03	10.65	10.67
D.1.Burning canes(CH4+CO+Nox),Kg/TC	2080	20.80	20.84
Embedded Energy	56.05	0.56	0.56
TotalCO2e per ha	9981.27	86.54	100.00
CO2e per TC		99.81	
CO2e /Lkg sugar		49.91	
CO2e /kg sugar		1.00	
Ratoon Cane			
A.Ratoon cane Establishment	61.10	0.84	1.17
B.Care and Management	374.93	5.17	7.21
C.FARM INPUTS	1514.46	20.89	29.12
N (NOx)CO2e	880.00	11.59	16.92
D.HARVESTING& Hauling	831.76	11.47	15.99
D.1.Burning canes(CH4+CO+Nox),Kg/TC	1508.00	20.80	28.99
E.Embedded CO2e(Machines)	31.29	0.43	0.60
TotalCO2 e per Ha	5201.55		100.00
CO2 e /TC (Kg)		71.75	
CO2 e /Lkg sugar ,kg		35.87	
CO2 e /kg sugar ,kg		0.72	

The summarized carbon dioxide emission are as follows:

	Kg CO_2e	% of Total
Crop establishment	505.73	7.22
Care and management	315.62	4.50
Farm inputs	1916.66	27.35
NO_X - CO_2e	948.20	13.53
Harvesting and Hauling canes to the mill	948.31	13.53
Burning canes	1794.00	25.60
Embedded emission	43.67	0.62
Total	7591.41	

The carbon footprint of sugarcane production are as follows: Per ha = 7591.41 kg CO_2e equivalent ; Per TC = 85.78 kg CO_2e equivalent; Per Lkg = 42.89 kg CO_2e equivalent , Per kg raw sugar = 0.86 kg CO_2e equivalent. These figures are the average of 1 plant cane and 1 ratoon cane

Farm inputs are the highest source of carbon footprint at 27.35% of total emission. If the CO_2e equivalent emission from Nitrous Oxide as a result of nitrogen application, then the proportion of farm inputs become 41% of the total emission. The other major source of emission is harvesting and hauling at 13.53% of the total. The larger emissions come from the emissions of green house gases (GHGe) during cane burning either before or after harvest. The direct CO_2 emissions from burning canes (cane biomass is 41% carbon) were excluded as they mixed in the biotic CO_2- cycle which means they are re-fix in the next crop photosynthesis. But there are other gases (CH_4, CO, and N_2O) that are emitted in burning canes either before or after harvest. Their estimated contribution to the total CO_2e was 25.6% of the total at 7591.4 kg CO_2e equivalent. Adding this emission to the harvesting component of carbon footprint, its contribution becomes 39.13%. The pictures below show the practice of burning the cane trashes in Negros Occidental, Philippines.

The practice of burning the sugarcane trash after harvesting To facilitate ratooning operations *i.e.* stubble shaving, interrow cultivation. Photo taken by: TC Mendoza, Negros Occidental, Philippines

Farm inputs at 40.88% of the total carbon dioxide emission and cane burning at 39.13% are the 2 largest source of CO_2e in sugarcane production. Added together, they contribute 80% of the total emission at 7591.41 kg CO_2-e/ha. This is being emphasized since the next step is to find out how to minimize the carbon footprint of sugar production of the 2 major sources.

Using the 7591.41 kg CO_2 emission equivalent per ha or at 85.78 kg CO_2e per TC, then, the CO_2e equivalent can be reduced. As shown in Fig 1, No cane burning is correlated to re-building or restoring soil quality by gradually increasing the soil organic matter (SOM). Ultimately, a reduction in fertilizer application.

The different options or combinations in reducing the carbon footprint of sugarcane production are shown in Table 2.Relative to the *practice –as usual* emission at 52.27 kg CO_2e equivalent, the reductions are summarized as follows:

a) 3 ratoon cycle & 30% fertilizer reduction → 41.03 kg CO_2e per TC (21.5% reduction)

b) *4 ratoon cycle & 50% fertilizer reduction → 34.0 kg CO_2e per TC (34.0% reduction)*
c) *5 ratoon cycles & 70% fertilizer reduction → 28.2 kg CO_2e per TC (46% reduction)*

The best option could be realized under 5 ratoon cycles, minimal fertilizer and hauling by rail as follows…..

By rail + 95 kg N only → 20.08 kg CO_2e/TC (61.58% reduction)
By rail +50 kg N only → 16.15 kg CO_2e/ TC (69.10% reduction)
By rail and organic farming (0 N) would lead to 82.% reduction.

Hauling by rail was done in the past. It was being done in Tarlac up to the 2008. It should be done again as it is the least energy requiring (Zelmer, 2009; Steffanie and Pekol, 2012). While there are many challenges to be addressed in hauling canes by rail, using bigger and more fuel efficient engines could be done by improving the road conditions.

Table 2. Relative Carbon footprint (Kg CO2 e) per Ton Cane (TC) in different options/combinations and percent reduction in carbon dioxide emission **

A. Current Practice/ System(*Benchmark data*)		**Kg CO2e/TC**	
a. Crop establishment (1PC + RC)		6.34	
b. Fertilizer		30.72	
c. Hauling		10.85	
d. Other (machines & care & Management of the crop)		4.36	
TOTAL Kg CO2e/TC		52.27	
KgCO2e/LKg		26.14	
KgCO2e/kg raw sugar		0.52	
B. Options/ Combinations (Ratoon Cycle)	RC3	RC4	RC5
Fertilizer Reduction	0.3 Fert.	0.5 Fert.	0.7 Fert.
	KgCO2e/TC		
a. Crop establishment	6.06	5.98	5.9
b. Reduction in fertilizer	21.5	15.05	8.83
c. All big trucks for hauling	9.11	9.11	9.11
d. Other	4.36	4.36	4.36
TOTALKgCO2e/TC	41.03	34.5	28.2
KgCO2e/LKg	20.52	17.25	14.10
KgCO2e/kg raw sugar	0.41	0.35	0.28
% reduction relative to A	21.5	34.0	46.0
C. Ideal/ Best Option		KgCO2e/TC	

	*A**	*B***	*C***
a. Crop establishment (RC5)	5.90	5.90	5.90
b. Fertilizer (90 Kg* , 50Kg, 0 N)**	8.83	4.90	0.00
c. Haul by rail	0.99	0.99	0.99
d. Other	2.61	2.61	2.61
TOTAL*KgCO2e/TC*	18.33	14.40	9.50
KgCO2e/LKg	9.17	7.20	4.75
KgCO2e/kg raw sugar	0.18	0.14	0.10
% reduction relative to A	64.93	72.45	81.83

RC3,RC4, RC5-3,4,5 ratoon cycles, respectively
0.3 fert,0.5 fert.,0.7 fert.- 30,50,70% reduction in fertilizer
A, B**,C**- 90 kgN, 50 kg N, 0 kg N, respectively*

In cane growing, trash farming or no burning canes is the main agricultural practice that would significantly cut down the fossil fuel energy-based carbon dioxide emission (CO_2e) of sugarcane production .No cane burning (which translate to an agriculture practice of trash farming) hits the 2 interrelated sources of carbon emission for sugarcane production which are the fertilizer and crop establishment. On fertilizer/ nutrients, no burning canes conserves the 3 macronutrients (N, P, K), cane burning oxidizes 90% of nitrogen (burns 90% of trash IPCC 2006), about 20-25% of phosphorus and about 70% of potassium. No burning means conserving nutrients as shown in the Table 3. No burning canes/trash farming decreases the amount of fertilizer applied (Dosayla,1994).As early as 1956, Pineda had reported it and Abrigo *et al*. (1981) showed that organic fertilizer from cane trash as soil ameliorant improves sugar yield.

Table 3. Nutrients conserved, energy preserved and the equivalent CO2 emission trash when no Burning is done .

	Kg/ton trash	**Nutrients in Trash (kg/ha)**	**Energy Saved (LDOE)**	**CO_2e Equiv. (kg/ha)**	**PhP value of Nutrients**
Nitrogen	2.87	32.43	62.75	810.40	1153.10
Phosphorus	0.02	0.23	0.02	0.02	12.77
Potassium	4.46	50.40	10.23	3.69	1679.93
			73.00	814.12	2845.81
N-fixation in trash(10kg/ton)	10	111.30	239.295	3090.26	3519.45
Saved energy due to more ratoons(2)			65	257.40	1560.00

TOTAL	312.30	3904.37	7925.26

Average weight of unburnt trash=11.13 t per ha
Energy value of nutrients: N=2.15 LDOE/kg; P=0.351 /DOE/kg ; K= 0.29 LDOE/kg
Carbon dioxide emission of nutrients/kg : N=12.913kg ; P=1.1kg ; K =0.361 kg CO_2e/kg

No burning increases the ratoon cycles without significant yield decline. In fact, ratoon yield increases in trash farming. No burning of canes decreases the greenhouse gas emission (GHGe) in 2 ways: direct and indirect emission: a) the direct emission comes from the 0.41 carbon content of the crop biomass (carbon has 3.7 times CO_2 equivalent, C-CO_2). But in the audit of carbon footprint, the CO_2 direct emission from organic C was not included. It was the argument that it is biotic CO_2, hence, it re-enters back into the biotic CO_2 cycle of the next crop photosynthesis. This is correct! But conversely without burning, it is getting back(sequestering) previously emitted CO_2 due to cane burning as shown in Fig. 1 below.

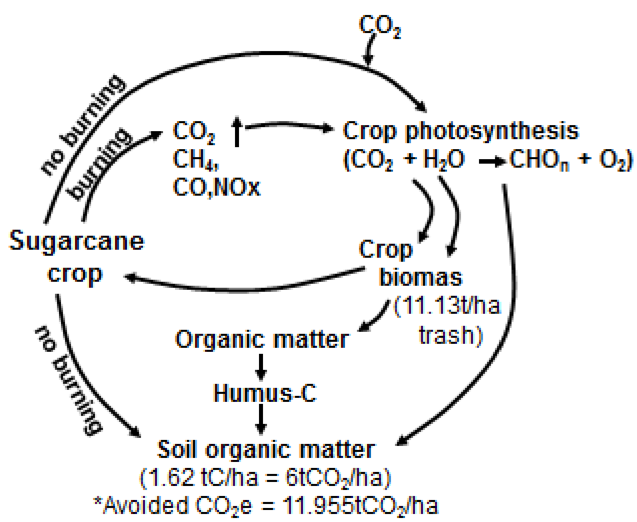

Fig.1. **The CO2 cycle and how no burning cane make sugarcane production build-up soil organic matter(SOM) and carbon dioxide sequestering.**

No burning preserves the biomass (organic matter) which will decompose later on. But the process of decomposition does not liberate all carbon as CO_2. Some become stable humus – C and are tightly held (sequestered) in the soil as soil organic matter. Lal (2004) estimated that about

15% of organic matter becomes SOM .The humus forming compounds are much more resistant to microbial decomposition than freshly applied crop or plant residues (Magdoff, 2004; Scheewe, 2002).

Using the unburnt trash of 82.5 TC/ha is about 11.13 t/ha (9.9 -12.38 t/ha = 11.13 t/ha average). About 15% of 11.13 t/ha becomes humus- C (1.67 tC/ha). This is equivalent to 6 tons CO_2e t/ha. No burning is sequestering or getting back emitted CO_2 by the CO_2 emitting processes and inputs in sugarcane production (mechanical operations, fertilizer, pesticide inputs). At 11.13 t/ha unburnt trash, the foregone emission of the carbon (0.41) content in the trash is about 15.20 tCO_2e/ha (11.13 t/ha x 0.41 x 3.7 CO_2-C x 0.90 burnt (IPCC 2006). Conversely, this is the amount to be used by the crop in the next crop photosynthesis to produce the biomass. But burning emits non –CO_2 GHGe (CH_4, CO, N_2O). Earlier, (Mendoza 2014) had quantified CO_2e equivalent of CH_4, CO and N_2O. The CO_2e equivalent summed up to about 1.794 t CO_2e per ha. Add this to the sequestered CO_2 to the soil as humus-C (1.794 tCO_2 + 6 t CO_2e equals 7.794 tCO_2e. Increasing carbon sequestration in the soil is one of the 2 ways in decreasing the atmospheric concentration of CO_2.. The largest carbon pool in terrestrial ecosystems and its organic carbon content is three times higher than the plant carbon pool (Eswaran *et al*., 1993; Lal 2003; Falkowski *et al*., 2000).

There is also avoided emission due to N-fixation while there is trash decomposition at 10 kg/ton trash. The avoided emission due to N-fxation is 3.090 t CO_2e (10 kg N x 11.13 t/ha x 12.914 kg CO_2e/ kg N).

Trash farming extends the ratoon cycle from 1 ratoon (RC_1) to 5th ratoon (RC_5) (Brazilians ratoon their canes up to 6 times). The saved energy converted into CO_2e equivalent amounts to 0.257 t CO_2e for the additional 4 ratoons. Hence, the total avoided CO_2emission equivalent is about 12.0 t CO_2e/ha as listed below:

Humus-C sequestered CO_2e	=	*6.0 t CO_2e*
Avoided emission of CH_4, CO, N_2O	=	*1.794 t CO_2e*
Avoided emission due to N-fixation	=	*3.09 t CO_2e*
Avoided emission due to more ratoons	=	*0.257 t CO_2e*
Total	=	*11.955 t CO_2e*

The Ex-Ante Carbon Balance

The calculated ex-ante carbon balance (Table 4) of sugarcane production was 8,654.43 kg CO_2 eq. per ha. The carbon sequestered and/or avoided due to non-burning was 10,110.5 kg CO_2 eq. per ha and the avoided emission as a result of non-burning summed up to about 3,740.65 kg CO_2 eq. per ha. The sum of 2 = 13,850 kg CO_2 eq. per ha. Three (3) ways were done to calculate the ex-ante carbon balance. The first was when all the sequestered and avoided emissions were deducted from benchmark carbon footprint (Net Carbon = B-A). About 5,164 kg CO_2 per ha was the ex-ante carbon balance. Others will point out N-fixation cited at 10 kg N per ton of trash may not be realized fully. Taking out the equivalent avoided emission due to N-fixation, the ex-ante carbon balance was 3,759 kg CO_2e. Also, some may point out the farmer may not reduce fertilizer application even without burning despite the coupled N-fixation while the trashes are decomposing but still there was positive carbon balance at 1,455.82 kg CO_2 per ha.

Table 4. / Ex-Ante Carbon Balance : *Practice-as usual* (1) and the *High Input cane*(2)

SCENARIO	***Practice-as-***
	usual(1)
A) Carbon emission(with burning)	Kg CO2e/ha
→ Crop establishment	950.35
→ Crop care and mgt.	256.31
→ farm inputs	2318.93
N(Nox)	1016.40
→ harvesting/hauling	1065.03
→ Embedded emission	56.034
→ Burning canes(CH4, CO, NOx)	2,080.00
TOTAL (A)	**8654.43**
B) Carbon sequestered/Avoided emission	
B.1 Carbon sequestered due to	
No burning	**10110.25**
Humus-C (SOM)	
→ roots (0.508*3.7)	1879.60
→ stumps(0.555*3.7)	2053.50
→ Trash/tops(0.15*11.13*3.7)	6177.15
B.2 Avoided emission	**3,740.65**
CH4, CO2, Nox	1,794.00
Reduced application of N due to :	
Unburnt nutrients (NPK)	
Nitrogen(2.87*11.13*12.914)	412.51

Phosphorus(0.02*11.13*0.55*3.96)	0.48
Potassium(	96.32
Nitrogen fixation -	
Average: 10KgN/ton trash	1,437.33
TOTAL (B)	**13,850.90**
Net Carbon (B - A)	**5,196.47**
Net Carbon (B - A) w/o N-fixation	3,759.14
Net Carbon (B - A) w/o Avoided emission	1,455.82

Note: Tonnage yield: 82.25 TC/ha ---> 11.13 tons trash

The Synthesis and Recommendation

Of the 3 major sources or contributors to carbon emission, crop establishment appeared the lowest at 15%, farm inputs 51% and hauling 25%. The first 2 are interrelated. Ratoon crop establishment reduced considerably the carbon dioxide emission by 40% relative to plant cane establishment. It is tempting to quickly suggest to planters that they prolong ratoon cycles from 1 to 5 or 6 as practiced in Australia or Brazil. But a 15-20 TC/ha decrease in ratoon yield is unacceptable especially for those planters who simply lease the lands they are cultivating.

It is anticipated that the price of oil will be increasing with time. Extending ratoon cycles is justified as it will reduce energy bill considerably from $RC_1 \rightarrow RC_6$ =74.5 LDOE per ha per year or 447 LDOE for 6 years 5 ratoon cycles .

Breeding and selection of varieties that could thrive up to 6th ratoons is necessary. Sugarcane planters and government R/D institutions partnership should be done. Large area is needed for setting-up selection/ evaluation trial for varieties exhibiting long ratooning potential. Basic research on parental development and identification of parents from the exiting germplasm and cultivar types that ratoons well must also be funded.

Reducing carbon footprint in sugarcane production is synonymous to *STOP* cane burning. Reduction in N-fertilizer usage can only be done without burning the 12-20 tons of trashes at harvest. It is correct to haul back mudpress+mill ash but they are only 4% of tonnage. Trash is about 12-15 % of tonnage.

The ex-ante carbon balance showed that sugarcane production is carbon sequestering (carbon negative) due to the avoided emission mainly due to a) direct C-sequestration from humus-C incorporated in the soil as soil organic matter; b) avoided emission of CH_4, CO, N_2O ; and c) avoided emission due to

N-fixation leading to reduced N-fertilizer (90-150 kg/ha), instead of the 220-300 kg/ha in the current system, the avoided emissions for the energy intensive plant cane establishment every other year if ratooning could be extended up the 5th or 6th ratoons as practiced already in Brazil and Australia. The other hidden benefits are on embedded energy of machines, soil erosion control, pollution (N-eutrophication of bodies of water) and the health hazards of burning etc.

A sun loving crop like sugarcane fixing carbon dioxide through the C4 pathway is the crop that can sequester more CO_2. Grasses like sugarcane plays an important role in countering CO2 emissions and global warming. They are able to process plantstone carbon also referred to as phytolith occluded carbon. *Plantstones are microscopic grains of silica in plant leaves, particularly grass-based pastures and crops such as sugarcane and wheat. During plant growth a small proportion of organic carbon becomes encapsulated within the microscopic silica grains. Regardless of whether the plant dies, burns or is harvested, the carbon entrapped in the plantstone is highly resistant to decomposition (Yang et al.,2015; Parr and Sullivan, 2010;).*

As a whole, sugar production from sugarcane can more than comply with the 70% carbon emission reduction under COPI 21 agreed upon by 195 nations. In the next 10-20 years, if 80% of the planters growing sugarcane could adopt No burning/trashfarming system in sugarcane production and sugar mills could integrate COGEN, it could even be more energy empowering as the excess electricity generated could be sold to the grid now (Demafelis *et a*l.,2016; ESMAP,1993; EDUFI,1994; Doon and Thompson,1998). Both the farm and the mill could be carbon negative**.**

The main agricultural practice that will significantly cut down the energy bill and the total carbon dioxide emission (CO_2e equiv.) of sugarcane production is *No cane burning* which translate to an agriculture practice called trash farming that….

→ *Decreases the energy bill/ carbon dioxide emission of sugarcane production as it hits the main 2 interrelated sources which are the fertilizer and crop establishment. On fertilizer/ nutrients, no burning canes conserves the 3 macronutrients (N, P, K). No burning means conserving them.*

→ *No burning increases the ratoon cycles without significant yield decline and yield increases in trash farming.*

→ *No burning/trashfarming transformed the energy-intensive and carbon emitting nitrogen fertilizer starved sugarcane production into carbon sequestering/avoiding systems*

The challenge now is *how do we STOP burning of canes before and after harvest.*

Trash shredding /trash farming practice in Eastern Batangas , Luzon Philippines . Photo taken by :TC Mendoza

Currently, there are already sugarcane planters whore not burning sugarcane trashes after harvesting and they are into trash farming already. In Eastern Batangas, Luzon, Philppines, the planters use tractor mounted trash shredder to facilitate the emergence of shoots to re-establish the ratoon canes, to hasten decomposition and to minimize the risks of the thick trashes to be burned and to facilitate interrow cultivation. In Negros, Visayas, Philippines, the cane workers piled the trashes after harvesting in between rows of the sugarcane .These are shown in the set of pictures above.

Trashes are piled between rows, planters practice in Northern Negros, Visayas, Philippines. Photo taken by :TC Mendoza

An agro-environmental Protocol must be formulated and be agreed upon by the planters association and the government (SRA) for implementation in the different sugarcane producing provinces in the country. Among others, the protocol must include the following:

a) *No cane burning (both before and after harvest of canes)*

b) *Soil conservation, soil erosion control on the side slopes of rivers by planting fruit and wood trees, bamboos and tall grasses (napier)*
c) *Adoption reduced tillage and contour planting of sugarcane in sloping areas. A hole method of Planting is proposed (Annex D)*
d) *Implement the simultaneous production, protection, preservation (3 Ps of agro ecosystems) by planting trees (wood trees, fruits) for every 100 hundred rows or lesser, around perimeter line or property boundaries or on land patches where there many stones or are unsuitable for cane growing. These trees will serve as wind and fire break and to have the unique ecosystems services.*

Combine harvested canes have already partially shredded tops and leaves as they are cut into pieces. In Australia, 100% of their canes are combine harvested. Also, in Brazil, mechanized harvesting is being promoted to eliminate the need of trash shredding. Combine harvested canes are no longer burned as ratoon tillers re-growth and succeeding ratoon cane management are not hampered. Furthermore, the Green Agro-environmental Protocol must also be complemented with the adoption of Good Agronomic Practices (GAP) in cane growing to increase yield. These are as follows:

1) *Selection/ planting of location adapted high yielding sugarcane cultivar*
2) *Sourcing of cane points to healthy canes (plant cane or even ratoon canes which still give 100TC/ha and above). Removal of leaf sheath ad selection of good/ healthy cane points at planting time.*
3) *Adequate land preparation to establish good plant cane (varies with soil type and weather)*
4) *Drainage canals are established or re-established during land preparation or before planting*
5) *Depending on nutrient content (soil analysis) and previous crop performance, adequate nutrients be applied. The calculation of externally sourced chemical fertilizer shall be based on the indigenous nutrient supply. (A simple computerized method (excel) is already done (Mendoza 2012).*
6) *Weeds are adequately controlled through cultivation and manual weeding as the need arise.*

Conclusion

The hottest spot in sugarcane production is the use of nitrogen fertilizer. But the use of fertilizer is related to crop establishment particularly in the ratoon canes. The high carbon footprint of fertilizer nitrogen can be offset through no burning / trash farming. In fact, the calculation showed that all the emissions of carbon dioxide are compensated and made sugarcane production into carbon sequestering through the humus-C in the soil organic matter plus the avoided emission of the fertilizer saved when not burned and the coupled

N-fixation when sugarcane trash is decomposing and the prolonged ratoon cycles..

The monetary value of no burning/ trash farming is big if adopted by many planters. The commitment of the Philippine president during the COP21: UN climate change conference held in Paris, on December 2015 of 70% reduction in CO_2 emission could be more than achieved. This could be done by promoting the adoption of Green Agro-Technical Protocol and Good Agronomic Practices .

The government investment on research and extension program to promote its adoption and its impact on the future of Philippine Sugar Industry will be huge. Giving the planters the peso value of the avoided emissions ($40/t$CO_2$ x 4tCO_2 per ha per year = $160/ha or *Php8,000*, 1$= PhP50) due to no burning canes will be a big incentive to the sugarcane planters.

Acknowledgement

Special gratitude with thanks is extended to the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA) for bestowing on the author one of the Regional Professorial Chair Awards for AY 2015-2016 (Ref. No. GCS 15-2123. This award has enabled me to synthesize data and quantify the many benefits on the practice of trash farming in sugarcane production. More important are the planters who were doing the practice now and adjusting field operations so that sugarcane trash will not be burned.The major part of this paper was discussed during the Fifth International Conference on Integration of Science and Technology for Sustainable Development 2016 (5th ICIST 2016) with a theme "Water conservation, Biological Diversity, Food and Agriculture" 2016 ICIST, held at Southern Shan State, Myanmar

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(Received: 23 Febrary 2017, accepted: 27 February 2017)