Energy use and CO_2 emissions of sweet potato production in Tarlac, Philippines

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Abstract: In this study, the energy use and carbon dioxide (CO_2) emission of sweet potato production in Tarlac, Philippines were evaluated. Data were collected from 180 farmers using structured survey questionnaires and face to face interview. Accordingly, the total input and output energy of sweet potato production was 29326.78 and 53885.90 MJ ha-1, respectively. Chemical fertilizers and diesel fuel provided the biggest portion of the total energy consumption in sweet potato production. The energy use efficiency, specific energy and energy productivity was 1.84, 1.95 MJ kg^{-1} and 0.51 kg MJ^{-1}. Indirect and non-renewable forms of energy dominated the share of the total input energy. The total GHG emission of sweet potato production was 1432.18 kg CO_{2eq} ha^{-1} (0.095 kg CO_2 kg^{-1}). Non-renewable sources of energy such as diesel fuel and chemical fertilizers were the main contributors of GHGs emission at 53.35% and 43.36%, respectively. The use of renewable sources of input energy can lead to lesser GHG emission, more sustainable and environment-friendly agricultural production system for sweet potato. Energy management should be considered as vital strategy for resource conservation, climate protection and to promote sustainable agriculture for sweet potato production.

Keywords: sweet potato, energy, greenhouse gases, carbon dioxide

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1 Introduction

Sweet potato (*Ipomoea batatas L.*) is one of the most important crops grown worldwide. It is the seventh most important food crop in the world. Because of its nutritional value, the demand for sweet potato in the fresh and process market is continuously increasing. Sweet potato is one of the substantial source for starch, sugar, alcohol, flour and other industrial products (Lee et al, 2006; Adenuga, 2010). Currently, it is one of the energy crops like corn, cassava, sugarcane and sweet sorghum because of its potential source as feedstock for bioethanol production. With the current technology, about 12.5% of bioethanol can be recovered from processing of fresh sweet potatoes (Qiu et al., 2010). Like other biomass fuels, the conversion however of sweet potato into bioethanol is challenged whether it produces a positive net energy or it is an environment-friendly processing technology.

In the Philippines, sweet potato is one of the most important cash crops due to its low input requirements. The average annual production of sweet potato in the country is 532,443 metric tons (BAS, 2014). The yield in sweet potato production can be increased through varietal improvement, improved crop management practices as well as reduced postharvest losses. Tarlac is one of the top producing sweet potato provinces in the country and considered as the main supplier of sweet potato roots to the famous fruits and vegetables marketplace in the country called “Divisoria market”. Increasing the yield of sweet potato production using high-yielding clean planting materials, chemical fertilizers and pesticides has been done by most farmers in the province of Tarlac. These systems however have increased the energy input per unit area. Increasing the yield of sweet potato

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production is linked with higher energy input requirement both in the production and postproduction operations.

Energy is one of the main elements in modern agriculture as it depends heavily on fossil and other energy resources. The increase in input energy to obtain maximum yields may not usually obtain high profits due to the increase also in the cost of production (Erdal et al., 2007). Effective use of energy in agriculture is one of the conditions for sustainable agricultural production since it helps to save financial resources, conserve fossil fuels, and reduce air pollution. Therefore, there is a need that energy must be used efficiently to achieve increased production and productivity and ensures competitiveness and sustainability of agriculture (Ozkan et al., 2004, 2007). In this case, an assessment of the existing energy utilization must first be done to establish concrete data and information as basis for introducing potential technology intervention to further enhance energy efficiency of sweet potato production.

In relation to energy, the problems of GHG emission and global warming potential (GWP) are also critical due to excessive use of energy in the production system (Khoshnevisan et al., 2013). As a result of agricultural activities, greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are produced and worsened the natural greenhouse effect in the environment. It is reported that the agricultural sector contributes significantly to the atmospheric GHG emissions with 14% of the global emissions (IPCC, 2007). To date, there have been several studies on estimating GHG emissions in the production system of some agricultural crops but so far no studies have been conducted to analyze energy use and GHG emissions of sweet potato production in the Philippines.

For this purpose, the input-output energy, energy efficiency and GHG emissions of sweet potato production in the province of Tarlac were determined in this study. This research was undertaken to establish baseline data on energy and GHG emission in sweet potato production as basis to identify opportunities for improving the environmental aspects at various points in the entire production. Moreover, the information that would be generated could serve as basis in the decision making process of the Philippine-government for the application of agricultural policy that promotes an environmentally-sound crop management design leading to more efficient and sustainable sweet potato production system in the Philippines.

2 Materials and methods

2.1 Sweet potato production system boundary

Sweet potato production system at farmer-level of operation as depicted in Figure 1 was evaluated. The pre-harvest operations included the crop cultivation and management while the postharvest operations considered were harvesting (vine removal and uprooting of tubers), in-field gathering, sorting and bagging and in-field hauling. In this study, the analysis started from production-to-farm-gate boundary, which provided flexibility for analyzing different crops with various end uses (e.g., food, feed, fuel) was considered. Other on-farm processing beyond in-field hauling operation was not included because it is assumed that the sweet potato is sold as fresh tubers in the market.

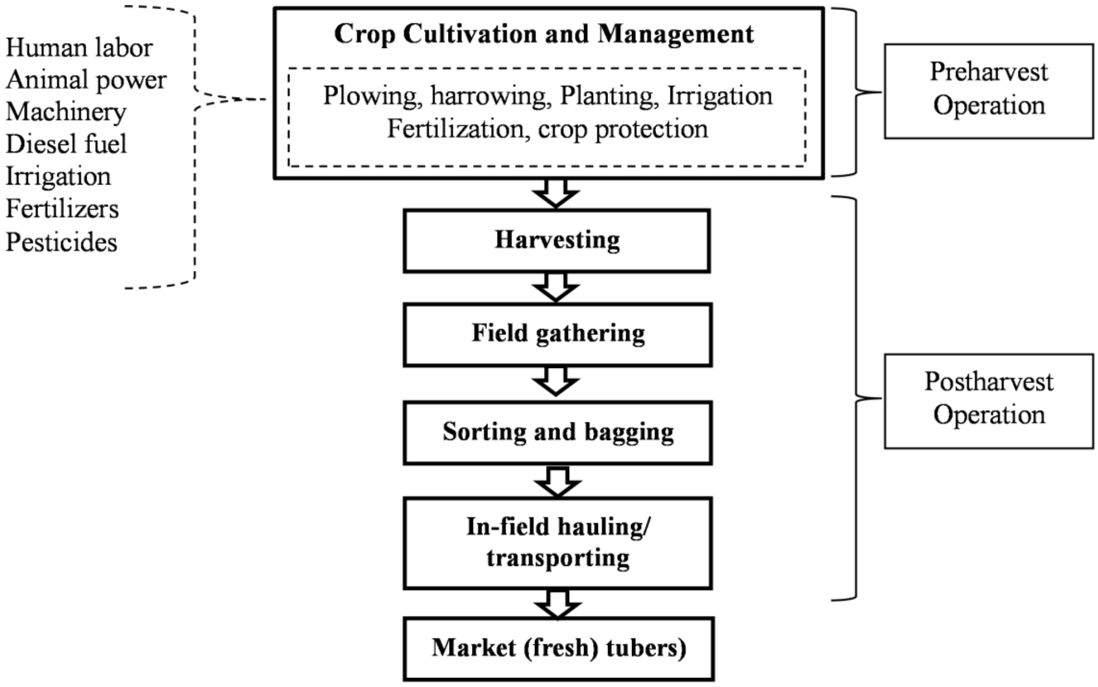

Figure1 Sweet potato production system boundary used in the assessment

2.2 Data collection and analysis

Data and information were collected from a total of 180 sweet potato farmers/producers using structured survey form questionnaires. The collected information included the sweet potato production systems from land preparation, crop management, harvesting and in-filed hauling of fresh sweet potato roots. The input requirements included planting materials, human labor, animal power, machinery, diesel fuel (used in land preparation, irrigation, harvesting and in-field hauling), fertilizers and pesticides for crop management while yield in fresh sweet potato tubers was specified as output. The sample size was determined using Equation 1 (Yamane, 1967).

$$n = \frac{N}{1 + Ne^2} \quad (1)$$

Where *n* is the required sample size; *N*, the number of sweet potato farmers/producers in target population and *e*, the acceptable error (permissible error was chosen as 5%).

2.3 Assessment of energy input-output of sweet potato production system

The human labor, animal power, machinery, diesel fuel, chemical fertilizers, chemical pesticides and irrigation were identified as inputs to assess the amount of energy usage while the sweet potato roots in fresh form as output. The amount of each input was multiplied with the energy coefficient equivalent as listed in Table 1 to calculate the energy use per hectare. Sweet potato farmers commonly used four-wheel tractors and other agricultural equipment for their land preparation, planting, harvesting and in-field hauling. Thus, the machinery energy input is calculated using Equation 2 (Bautista and Minowa, 2010):

$$MIE = \frac{MEC \times MW}{LM \times EFC} \quad (2)$$

Where *MIE*, is the machinery input energy in MJ ha^{-1}, *MEC* is the machine energy coefficient at 108.9 MJ kg^{-1}, *MW* is the machine weight in kg, *LM* is the life of machine at 9600 h and *EFC* is the effective field capacity of the machine or equipment in ha h^{-1}.

The energy input was examined as direct and indirect, renewable and non-renewable forms of energy. Energy indicators such as energy ratio (*ER*), energy productivity (*EP*), specific energy (*SE*) and net energy (*NE*) were determined using Equations 3 to 6, respectively (Yousefi et al., 2014a).

Energy ratio is sometimes called EROI which means the energy return on energy investment (Andrea et al., 2014; Tieppo et al., 2014). It is an indicator used to determine the productivity and efficiency of energy in the crop production system. It is indicated that a little portion of the input energy is utilized in the production process if the ratio is high. On the other hand, most of the input energy is consumed to maintain the process if the ratio is low (Gagnon et al., 2009).

$$ER = \frac{Energy\ output\ (MJ/\ ha)}{Energy\ input\ (MJ/ha)} \quad (3)$$

$$EP = \frac{Sweet\ potato\ roots\ output\ (kg/\ ha)}{Energy\ input\ (MJ/ha)} \quad (4)$$

$$SE = \frac{Energy\ input\ (MJ/\ ha)}{Sweet\ potato\ roots\ output\ (kg/ha)} \quad (5)$$

$$NE = Energy\ output\ \left(\frac{MJ}{ha}\right) - Energy\ input\ \left(\frac{MJ}{ha}\right) \quad (6)$$

Table 1 Energy equivalent of inputs and output in sweet potato production system

Input/output	Unit	Energy, MJ unit^{-1}	Reference
A. Inputs			
1. Human labor	h	1.96	Mohammadi et al., 2010
2. Animal power	h	3.49	Pimentel, 1979
3. Machinery	kg	108.90	Pimentel, 1992, Kitani 1999
4. Diesel fuel	L	47.80	Pimentel, 1992, Kitani 1999, Esengun et al., 2006
5. Chemical Fertilizers			
a. Nitrogen, N	kg	78.10	Kitani., 1999
b. Phosphorous, P_2O_5	kg	17.40	Kitani., 1999
c. Potassium, K_2O	kg	13.70	Kitani., 1999
6. Chemical Pesticides			
a. Insecticides	kg	101.20	Ozkan et al., 2007
b. Herbicides	kg	238.00	Ozkan et al., 2007
c. Fungicides	kg	216.00	Ozkan et al., 2007
7. Water for irrigation	m3	0.63	Hatirli et al., 2005
A. Output			
1. Sweet potato roots	kg	3.59	Oke et al., 2013

2.4 Estimation of GHG emission of sweet potato production system

The amounts of GHG emissions from inputs in sweet potato production per hectare were calculated by using CO_2, N_2O and CH_4 emissions coefficient of chemical inputs (diesel, fertilizer-nitrogen, etc.). GHG emission can be calculated and represented per unit of the land used in crop production, per unit weight of the produced yield and per unit of the energy input or output (Soltani et al, 2013). The amount of CO_2 produced was calculated by multiplying the input application rate per hectare (e.g. diesel fuels, chemical fertilizers, herbicides and pesticides) by its corresponding coefficient enumerated in Table 2.

Emissions from farm inputs (diesel, nitrogen, phosphate, potash) were converted to kg CO_2eq. Greenhouse gases (GHGs) such as CH_4 and N_2O were converted to kg CO_2eq on the basis of their 100-year global warming potentials (GWPs), which are 1 for CO_2, 25 for CH_4 and 298 for N_2O (Eggleston et al. 2006). The total emissions of greenhouse gases are determined using Equation 6 (Kramer et al, 1999).

$$GHG\ emission = \sum GWPi \times Mi \quad (6)$$

Where Mi is the mass (in kg) of the emission gas. The score is expressed in terms of kilogram carbon dioxide equivalent (kg CO_{2e}).

Table 2 Gaseous emissions (g) per unit of chemical sources and their global warming potential (GWP) in sweet potato production system

Inputs, unit	CO_2	N_2O	CH_4	References
1. Diesel, L	3560.	0.70	5.20	Kramer et al., 1999
2. Nitrogen fertilizer, kg	3100	0.03	3.70	Snyder et al., 2009
3. Phosphate (P_2O_5), kg	1000	0.02	1.80	Snyder et al., 2009
4. Potash (K_2O), kg	700	0.01	1.00	Snyder et al., 2009
GWP CO_2 equivalent factor	1	298	25	Eggleston et al., 2006

Other farm inputs such as machinery and chemical pesticides (insecticide, herbicides and fungicides) were directly multiplied with their GHG emission coefficients presented in Table 3. The total GWPs (in kg CO_{2eq}) were integrated and determined the GWPs per hectare of sweet potato production.

Table 3 GHG emission coefficients of agricultural inputs

Inputs, unit	GHG Coefficient kg CO_{2eq} unit^{-1}	References
1. Machinery, MJ	0.071	Dyer & Desjardins, 2006
2. Chemical pesticides		
Insecticides, kg	5.1	Nabavi-Pelesaraei et al., 2014
Herbicides, kg	6.3	Nabavi-Pelesaraei et al., 2014
Fungicides, kg	3.9	Nabavi-Pelesaraei et al., 2014

3 Result and discussions

3.1 Energy input-output of sweet potato production

The inputs used and output in sweet potato production system in Tarlac with their energy equivalents and percentage share in the total input energy are summarized in Table 4. The average sweet potato yield was 15,010 kg ha^{-1} with an equivalent energy output of 53,435.60 MJha^{-1}. The total energy input in sweet potato production was 29,326.78 MJ ha^{-1} resulting to a net energy of 24559.12 MJ ha^{-1}.

Majority of the total input were contributed by chemical fertilizer (51.61%) followed by diesel fuel at 34.31% (Table 4). Among the chemical fertilizers, nitrogen played the highest share of 50.86%. Similar results have been observed in the production of other agricultural crops such as sugar beet (Asgharipour et al., 2012), irish potato (Pishgar-Komleh et al., 2012), wheat (Singh et al., 2007) and corn (Yousefi et al., 2014b) where chemical fertilizer, specifically nitrogen was the highest contributor of energy in the total input energy of most crop productions.

Table 4 Energy inputs and output of sweet potato production; Tarlac, Philippines; 2015

Inputs and output	Quantity per unit area, ha		Total energy equivalent, MJ ha^{-1}	Standard Deviation	% Share
A. Inputs					
1. Diesel	210.47	L	10060.77	626.91	34.31
2. Machinery	14.04	h	477.80	69.89	1.63
3. Animal labor	32.00	h	111.68	3.83	0.38
4. Human labor	726.00	h	1422.96	7.53	4.85
5. Irrigation water	3042.0	m^3	1916.46	61.63	6.53
6. Chemical fertilizers			15134.80	3090.94	51.61
Nitrogen –N	191.00	kg	14917.10	3046.02	50.86
Phosphorous- P_2O_5	7.00	kg	121.80	25.15	0.42
Potassium – K_2O	7.00	kg	95.90	19.76	0.33
7. Chemical pesticides	2.0	kg	202.40	49.02	0.69
Total Input			29326.86	3805.54	100.00
B. Output					
Sweet potato roots	15010	kg	53885.90	16404.87	100.00
C. Net Energy			24559.04	12974.64	-

3.2 Energy use per operation of sweet potato production

The energy consumed for each operation in the agricultural production system of sweet potato is presented in Table 5. It is evident that pre-harvest operation consumed most of the energy at 26327.41 MJ ha^{-1}, giving 89.77% share of the total input energy. The energy utilized by postharvest operation was 2999.45 MJ ha^{-1} with only 10.23% share in the total input energy of sweet potato production. Among the overall operations, the application of fertilizers provided the highest share of utilized energy (51.71%). This was followed by irrigation (24.28%) and then land preparation (11.05%). The results were predominantly contributed with the excessive used of nitrogen during the application of fertilizers and diesel fuel during irrigation and land preparation.

Table 5 Energy inputs per operation of sweet production; Tarlac, Philippines; 2015

Operation	Total energy equivalent MJha^{-1}		Energy Share, %	
Preharvest operation		***26327.41***		***89.77***
1. Land preparation	3241.07		11.05	
2. Planting materials production	156.80		0.53	
3. Transplanting	235.20		0.80	
4. Irrigation	7120.02		24.28	
5. Fertilizer application	15166.16		51.71	
6. Pesticide application	233.76		0.80	
7. Side dressing/hilling-up	174.40		0.59	
Postharvest operation		***2999.45***		***10.23***
8. Harvesting	1459.44		4.98	
9. Field gathering	235.20		0.80	
10. Sorting and bagging	156.80		0.53	
11. In-field hauling	1148.01		3.91	
Total Input		**29326.86**		**100.00**

3.3 Energy indicators of sweet potato production

Energy indicators such as energy ratio, energy productivity, specific energy and net energy of the sweet potato production are enumerated in Table 6. Energy ratio is generally used as an index to assess the efficiency of energy in crop production systems. Thus, the higher the energy ratio, the more efficient use of energy is attained in the crop production. Efficient use of energy resources is vital in terms of increasing production, productivity, competitiveness in agriculture as well as sustainability (Hatirli et al., 2006) of crop production systems.

The energy ratio calculated for sweet potato production was 1.84. This implied that the energy consumed in the production process has been replenished 1.84 times by the energy produced from harvested sweet potato roots. With this, the calculated specific energy value and energy productivity was 1.95 MJ kg^{-1} and 0.51 kg MJ^{-1}, respectively. This means that an input energy of 1.95 MJ is needed to yield one kilogram of sweet potato or 0.51 kg of sweet potato roots is produced per unit (MJ) input energy. Currently, there is limited or perhaps no studies on energy generated for sweet potato production. However, in some related studies, the value of energy ratio for potato of 1.71 (Pishgar-Komleh et al., 2012), 1.14 and 0.95 (Zangeneh et al., 2010), and 1.25 (Mohammadi et al., 2008) were close to energy ratio generated in this study (1.84).

Table 6 Indicators of energy use in sweet potato production

Indicators	Unit	Quantity
Inputs energy	MJ ha^{-1}	29326.78
Output energy	MJ ha^{-1}	53435.60
Energy ratio		1.84
Energy productivity	kg MJ^{-1}	0.51
Specific energy	MJ kg^{-1}	1.95
Net energy	MJ ha^{-1}	24559.12

3.4 Energy forms of sweet potato production

The forms of energy in the sweet potato production can be distributed into direct and indirect or renewable and non-renewable energies as presented in Table 7.

Indirect energy share of 53.93% dominated the direct energy share of 46.07% in the total input energy consumption for sweet potato production. This was attributed to the use of inputs such as chemical fertilizers and machinery. Majority of the total input energy share in the area of the study was non-renewable energy at 88.23% while the remaining renewable energy input was 11.77%.

Table 7 Total energy input in form of direct, indirect, renewable and non-renewable for sweet potato production

Indicators	Quantity, MJ ha^{-1}	Percent share, %
Direct energy [a]	13511.78	46.07
Indirect energy [b]	15815.00	53.93
Renewable energy [c]	3451.10	11.77
Non-renewable energy [d]	25875.68	88.23
Total energy input	29326.78	100.00

[a] *Includes human labor, animal labor, diesel, irrigation water*
[b] *Includes machinery, planting materials, chemical fertilizers, chemical pesticides*
[c] *Includes human labor, animal labor, planting materials*
[d] *Includes diesel, chemical fertilizers, chemical pesticides, machinery*

Based on the results, the level of dependence to non-renewable form of energy was generally high. This is mainly contributed by the large amount of chemical fertilizers and diesel fuel used in sweet potato production. It is expected that in modern agriculture production system, the use of non-renewable energy is greater than renewable energy. Apparently, low input sustainable crop production is more efficient than conventional production and far more efficient when organic farming is employed due to non-utilization of any agrochemical inputs (Mendoza, 2005). The introduction of organic farming and the use of renewable input resources are encouraged as a way to conserve fossil resources and promote sustainable agriculture.

3.5 Estimation of GHG emissions of sweet potato production

The amount of greenhouse gas emissions with the use of machinery and chemical inputs in sweet potato production was calculated and tabulated in Table 8. The total GHGs emission of sweet potato production was 1432.18 kg CO_{2eq} ha^{-1}. Highest share was observed for diesel fuel (53.35%), followed by chemical fertilizer (43.56%) and then machinery (2.37%). Among the fertilizers, nitrogen played the most important role with a share of 42.70%.

It is noted that diesel fuel and chemical fertilizer were the major contributors to the GHG emissions in sweet potato production system evaluated. The results also indicated that the use of more chemical and non-renewable inputs with the aimed to increase yield in sweet potato production would lead to more emission of greenhouse gases and global warming potential.

Table 8 GHG emissions from agricultural inputs in sweet potato production

Inputs	GHG Emission kg CO_{2eq} ha^{-1}	GHG Emission Share%
Machinery	33.92	2.37
Diesel fuel	764.13	53.35
Chemical Fertilizers		43.56
(a) Nitrogen, N	611.48	42.70
(b) Phosphorous, P2O5	7.36	0.51
(c) Potassium, K2O	5.10	0.36
Chemical Pesticides		
(a) Insecticides	10.20	0.71
Total GHG emission	1432.18	100.00

4 Conclusions and recommendations

Based on the results of this study, the following conclusions were drawn:

- Most of the energy input was contributed by chemical fertilizer (51.61%) followed by diesel fuel (34.31%). Among the chemical fertilizers, nitrogen gave the highest share of energy (50.86%) in sweet potato production.
- The energy use efficiency (ratio), specific energy, energy productivity and net energy calculated for sweet potato production was 1.82, 1.95 MJ kg^{-1}, 0.51 kg MJ^{-1} and 24108.82 MJ ha^{-1}, respectively.
- The energy utilized for sweet potato production is largely coming from non-renewable form of energy

(88.23%). Diesel fuel and chemical fertilizer are the major contributors to the emission of GHGs.

- To maintain and enhance the sustainability of sweet potato production, it is necessary to check the use of chemical inputs and non-renewable energy resources. Crop rotation with nitrogen (N)-stabilizer plants such as leguminous plants must be considered to reduce inorganic N fertilizer consumption.
- The use of green manure or organic fertilizer instead of chemical fertilizer should be considered to control the high rate of non-renewable energy utilization and reduce the amount of GHGs emissions.
- Cultural practices such as mulching using organic mulching materials can also reduce diesel fuel needed in irrigation.

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