Energy use and CO_2 emissions of eggplant production in the Philippines

Edgar D. Flores*, Renita S. M. Dela Cruz, Ma. Cecilia. R. Antolin

(Philippine Center for Postharvest Development and Mechanization, Department of Agriculture, 3120 CLSU Compound, Science City of Muñoz, Nueva Ecija, Philippines)

Abstract: The energy use and CO_2 emissions of eggplant production in the Philippines were analyzed from data collected from 202 eggplant farmers randomly selected from the two major producing provinces of Pangasinan and Quezon, Philippines. Accordingly, the input and output energy of eggplant production were 77,342.09 MJ/ha and 233,905.50 MJ/ha, respectively. Diesel fuel and chemical fertilizer contributed the largest share of energy used in eggplant production. Most of the input energy was utilized in preharvest operations among which the application of fertilizer and water irrigation consumed the largest energy. The energy ratio and energy productivity were 3.02 and 0.51 kg/MJ, respectively. Direct and indirect forms of energy constituted 60.93% and 39.07%, respectively, of the total energy consumption while the share of non-renewable and renewable forms of energy was 80.42% and 19.58%, respectively. The total GHGs of eggplant production was 5,843.35 kg CO_2eq/ha. Overall the production system considered that diesel, plastic bags and chemical fertilizers were the largest contributors to GHGs emission in eggplant production with 41.55%, 39.01% and 17.15% contribution, respectively. The total amount of carbon generated by applying agricultural inputs was 1,593.64 kgC/ha while the carbon produced from the yield of eggplant was 17,840.25 kgC/ha. The carbon ratio (sustainability index) in the production of eggplant was 11.18. Generally, the production of eggplant in the Philippines is a carbon neutral process because it does not emit carbon to the environment beyond the carbon output generated. Eggplant can be used for carbon sequestration because it exceeded by 11 times the input carbon emitted in the production process. The use of renewable sources of inputs such as organic fertilizers, biological pest control, biological mulching materials and bioplastics as packaging materials among others, can lead to lower GHG emission, more sustainable and environment-friendly eggplant production system.

Keywords: eggplant, carbon, energy, greenhouse gases, global warming potentials

Citation: Flores, E.D., R. S. M. Dela Cruz, and M.C. R. Antolin. 2016. Energy use and CO_2 emissions of eggplant production in the Philippines. Agric Eng Int: CIGR Journal, 18(1):138-148.

1 Introduction

Eggplant *(Solanum melongena L.)* is one of the most important vegetables in the world, with less than 2.5 million hectares devoted to the cultivation and an average annual production of 26,532,747 t (FAO, 2012). In the Philippines, eggplant is one of the banner crops and most popular lowland vegetables because of its inclusion as one of the basic ingredients of the most popular vegetable food viand in the country called "*pinakbet*". Currently, the Philippines is the number eleven producer of eggplant in worldwide, with an average annual production of 209,783.40 t (BAS, 2014). Pangasinan and Quezon provinces are the major producers of eggplant, contributing 30% and 13% share of the total Philippine eggplant annual output, respectively.

The government effort of providing the food needs of the growing population is focused on increasing agricultural production. However, with the development of agricultural production and move towards mechanization, there has been an increased reliance on energy resources. Utilization of energy in agriculture production has become more intensive due to the use of fossil fuel, chemical fertilizers, pesticides, machinery and electricity to provide substantial increases in food production (Pishgar-Komleh et al., 2011). The use of

Received date: 2015-08-12 **Accepted date:** 2015-11-09

***Corresponding author: Edgar D. Flores,** Philippine Center for Postharvest Development and Mechanization, Department of Agriculture, 3120 CLSU Compound, Science City of Muñoz, Nueva Ecija, Philippines

more intensive energy however has led to various environmental problems such as greenhouse gas (GHG) emissions, loss of biodiversity and pollution of the aquatic environment by chemical fertilizers and pesticides (Nemecek et al., 2011). It is reported that increasing energy input requirements may not always provide maximum profits due to the increased also in the production cost (Erdal at al., 2007). With this, the analysis of the energy utilization is usually undertaken to evaluate the efficiency of energy and environmental impacts of agricultural production systems (Ozkan et al., 2004). The effective use of energy will lead to sustainable production due to financial savings, fossil fuel preservation and reduction of air pollution (Pahlavan et al., 2012).

Agricultural crop production is considered a major consumer of energy and producer of greenhouse gases. Agricultural crop production requires direct and indirect consumption of fossil fuel which results in the emission of GHGs such as carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). It is reported that the agricultural sector contributes significantly to the atmospheric GHG emissions with 14% contribution of the global emissions (IPCC, 2007).

There have been several studies regarding the analysis of both energy use and GHG emissions in the production of agricultural crops such as corn (Yousefi et al., 2014a), sugar beet (Yousefi et al., 2014b;Tzilivakis et al., 2005), rice (Nabavi-Pelesaraei et al., 2014), wheat (Soltani et al., 2013; Khoshnevisan et al., 2013), potato (Pishgar-Komleh et al., 2012), cucumber (Pishgar-Komleh et al., 2013), tomato (Karakaya et al., 2011) and orange (Nabavi-Pelesaraei et al., 2013a), but so far no researches have been conducted regarding the energy use and GHG emissions of eggplant production, especially under Philippine condition.

In this study, the input-output energy, energy use per operation, energy indicators, GHG emissions and global warming potentials in eggplant production were analyzed. The net carbon and carbon efficiency ratio were also determined. The study was undertaken to provide baseline information as basis for improving the use of energy and environmental aspects at different operations in the entire production system of eggplant. Moreover, the information that would be generated could be used by the Philippine-government for the implementation of agricultural policy that promotes environmentally-sound crop management pattern leading to more efficient energy usage, improved yield and income of the eggplant farmers and reduction of the global warming potential of eggplant production in the Philippines.

2 Materials and methods

2.1 Eggplant production system boundary

The eggplant production system that was evaluated is illustrated in Figure 1. The pre-harvest operations included the crop cultivation and management while the postharvest operations considered were harvesting, in-field hauling, sorting and packing and transportation to trading post market. Other operation beyond transportation to trading post market was not included and assumed that the eggplant is sold as fresh vegetable in the market.

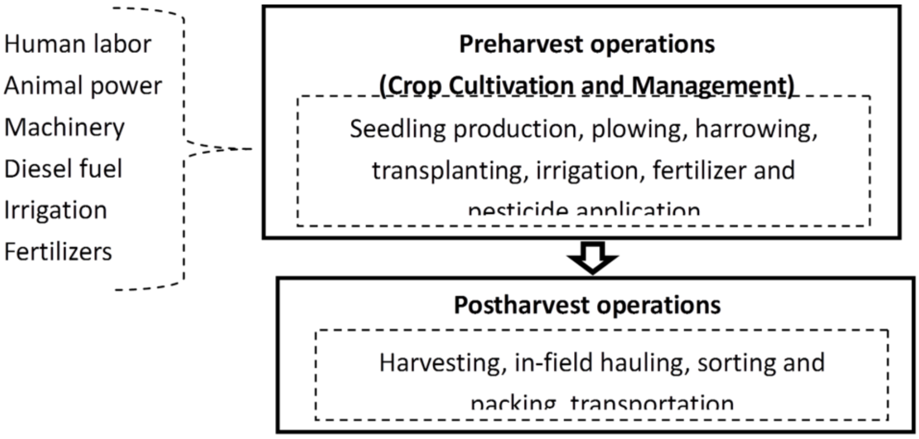

Figure1Eggplant production system boundary used in the assessment

2.2 Data collection and analysis

Farms were randomly selected from the major eggplant producing provinces of Pangasinan and Quezon, Philippines. Data on eggplant production were collected from 202 farmers/producers using survey questionnaires from the three top producing municipalities of Pangasinan such as Villasis, Asingan and Manaoag and the municipalities of Tiaong, Sariaya and Dolores for the province of Quezon. The sample size was determined using Equation (1) (Kizilaslan, 2009; Mobtaker et al., 2010).

$$n = \frac{N(s \times t)^2}{(N-1)d^2 + (s \times t)^2} \qquad (1)$$

Where: *n*, is the required sample size; *s*, is the standard deviation; *t*, is the t-value at 95% confidence limit (1.96); *N*, the number of eggplant farmers/producers in target population and *d*, is the acceptable error (permissible error was chosen as 5%).

The collected information included the eggplant production operations from land preparation, crop management and protection, harvesting, hauling, sorting and packing and transportation of fresh eggplant to trading post. The input requirements included human labor, animal power, machinery, diesel fuel (used in seedling production, land preparation, crop protection and management, irrigation, harvesting, hauling, sorting and packing and transportation), fertilizers and pesticides while yield in fresh eggplant was specified as output.

2.2.1 Crop protection and management (Preharvest operation)

2.2.1.1 Seedling production

The seeds are planted in a seedbed consisting of mixture of compost and garden soils. The seeds are planted not more than 1 cm deep in rows spaced 10-15 cm apart. The seedlings are watered regularly. One week before transplanting, the seedlings are toughened by gradually withholding water until they are temporarily wilted. The seedlings are normally transplanted four weeks from sowing. About 150 kg of dry green manure or organic fertilizers (mixture of compost and garden soils) are used. The seedbed is prepared by two persons in a day including regular watering and maintenance of the seedlings until transplanting. In this study, the energy utilized for seed production was derived from the amount of human labor and organic fertilizers used for seed bed preparation.

2.2.1.2 Land preparation

The land for transplanting is prepared by plowing once and harrowing twice. Afterwards, furrows are prepared 1.0 m apart by using either animal or tractor. The tractor (4-wheeled type) used for plowing has a capacity of 0.5 ha/h. For harrowing, hand tractor (two-wheeled type) with field capacity of 0.25 ha/h is usually used by the farmers. The same equipment is used for furrowing during transplanting. If the same equipment is used as furrower, the handtractor has a field capacity of 0.5 ha/h. In this case, the tractor operator (human labor) can operate 6.0 h/ha.

Based on actual observation, the total fuel consumption for land preparation was 54 L/ha.

2.2.1.3 Transplanting

Transplanting of eggplant seedlings is done four to five weeks after sowing. Generally, seedlings are planted in a hill at a distance of 0.5 m x 1.0 m. Result of the survey revealed that 12 persons are needed to plant a farm area of 10,000 m^2 in a day. This indicated that the total time devoted for transplanting of seedlings in a one hectare eggplant farm is 96 h/ha.

2.2.1.4 Irrigation

Irrigation starts after transplanting and is repeated as required. The soil should be moist at all times though water lagging must be avoided. As practice, eggplant is irrigated by furrow every one to two weeks depending on season and type of soil. Based on the survey, eggplant is irrigated 20 times from production until the last schedule of harvest. With this, the water pump is operated 20 times with 10 hours' operation. The amount of diesel fuel consumed per hectare was 20 L/ha. One person is required to manage the irrigation. The total water consumed for irrigation from production up to the last day of harvest was estimated to be 23,400 m^3/ha, considering the water pump rated capacity of 78 m^3/hand the pump efficiency ranges from 50% to 80% (Kitani, 1999).

2.2.1.5 Fertilizer application

Farmers usually practiced basal fertilization or the incorporation of fertilizers with the soil one to two weeks before planting. This is followed by side-dressing fertilizer every two to four weeks during its vegetative stage. Based on the survey, the typical amounts of fertilizers used by the farmers are 100-200 kg/ha for 16-20-0, 500-600 kg/ha for 14-14-14 and 300-400 kg/ha for 46-0-0. Typically, eight persons are required in fertilizer application for one hectare of eggplant in a day. With this, the total time duration for fertilizer application in one hectare eggplant farm is 128 h/ha.

2.2.1.6 Weeding and cultivation

Manual weeding is done by eggplant farmers three to five times during the growing season or as necessary. While weeding, hilling up by hands is also done three to four weeks after transplanting for partial control of weeds. This practice is usually undertaken to limit the population of insect pests like leafhoppers, shoot/fruit borers and epilachna beetles. Insect pest population can be prevented and controlled through sanitation such as weeding and removal of infected leaves and shoots, especially during the critical stage of plant growth. Infested fruits with fruitborers including deformed and damaged are also removed to prevent the spread of the pest. This operation is usually done by eight persons for hectare in a day.

2.2.1.7 Pesticide application

With the aim to control fruit and shoot borer (FSB), farmers frequently apply heavy doses of pesticides. Majority of farmers interviewed spray their eggplant two times a week; some even spray 60 to 80 times during the entire production period. Based on the survey, eggplant farmers usually consume 20 to 30 L of insecticides in one hectare for the whole production. For this operation, two persons are required for spraying one hectare in one day.

2.2.2 Postharvest operation

2.2.2.1 Harvesting

Eggplant farmers/producers in the study areas (Pangasinan and Quezon provinces) used similar maturity indices. The first fruits of eggplant are harvested 45-60 days after transplanting. At this condition, the eggplant has already attained the size sufficient for marketing. Other maturity indices such as size, breakage in the calyx and glossy purple in color (for colored variety) are also considered by some farmers. Harvesting is done carefully by using hands or a sharp knife. Harvested fruits are placed in a bamboo baskets, crates or sacks. Harvesting is done as early as 5:00 a.m. to 10:00 a.m. in the morning, depending on the area of production. About eight to ten persons are needed to harvest one hectare of eggplant. Harvesting is done once or twice a week and usually lasts for three to six months. Most of the farmers harvest their eggplant 30 times.

2.2.2.2 In-field hauling

While harvesting, all picked eggplants are hauled to a temporary shed in the farm or near the house of the farmer for sorting, cleaning and packing. Depending on the proximity of the production farm to the packaging shed, about four to six persons are required to haul the harvested eggplants for one hectare.

2.2.2.3 Sorting and packing

After hauling, sorting is done in the packing shed located within the farm or near the farmer's house. The fruits are classified according to size and quality. Fruits which are over-mature, with insect pest and diseases are considered rejects. However, those eggplants that are infested by pests but still edible are packed separately and sold at lower price. The sorted eggplants are packed in polyetelene (PET) plastic bags (20 x 30 inches, 0.00125 gauges). Classified good and semi-good are packed in 10 kg while rejects are packed in 15-20 kg. About six to eight persons are required to do the sorting and packing of harvested eggplant in one hectare.

2.2.2.4 Transport

Majority of eggplants from the study areas (Pangasinan Province and Quezon Province) are transported using jeepneys from farm to trading post markets in Urdaneta City, Tanauan City and *Sentrong Pamilihan ng Quezon*. Transportation of eggplants from farms to these markets usually takes 0.5 to 1.0 h of travel. Two persons are required to do the loading and unloading in 0.5 h. The jeepneys used and monitored in the study areas have an average fuel consumption of 7.5 L/h. In this study, the energy utilized for transport was obtained from the number of persons involved in the loading and unloading of eggplants from farm to market and the amount of fuel (diesel) consumed for transportation.

2.3 Assessment of energy input-output of eggplant production system

The machinery, human labor, diesel fuel used in several operations, chemical fertilizer, chemical pesticides and irrigation were specified as inputs to estimate the amount of energy usage while the eggplant in fresh form as the prorated 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.

Table 1 Energy equivalent of commonly-used production inputs and fresh eggplant as output

Input/output			Unit	Energy (MJ/unit)	Reference
A.	***Inputs***				
1.	Human labor		h	1.96	Mohammadi et al., 2010
2.	Animal power		h	3.49	Pimentel, 1979
3.	Machinery		h	108.90	Pimentel., 1992
4.	Diesel fuel		L	47.8	Pimentel, 1992;Kitani 1999;Esengun et al., 2006
5.	Organic Fertilizer		kg	0.30	Demircan et al., 2006 Ozkan et al., 2007
6.	Chemical Fertilizers				
	a.	Nitrogen (N)	kg	78.1	Kitani, 1999
	b.	Phosphorous (P2O5)	kg	17.4	Kitani, 1999
	c.	Potassium (K2O)	kg	13.7	Kitani, 1999
7.	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
8.	Water for irrigation		m^3	0.63	Hatirli et al., 2005
9.	Electricity		kWh	3.6	Asgharipour et al., 2012
10.	PET Plastic		kg	4.6	UNEP, 2009
A.	***Output***				
	Eggplant (fresh)		kg	5.9	Navabi-Pelesaraei et al., 2013b;Kitani, 1999

In determining the machinery input energy, the machine energy coefficient consisted of the energy quantity of the materials, energy utilized in the fabrication, transportation of the machine to the end-users and the energy used for repair and maintenance (Kitani, 1999) was considered. The average demand energy for equipment is equal to108.9 MJ/kg (Pimentel, 1992). This value was obtained from steel production energy of 62.8 MJ/kg, fabrication and assembly energy of 8.4 MJ/kg and repair and maintenance energy of 37.7 MJ/kg (Doering, 1980; Fluck, 1985). Thus, the machinery energy input is calculated using Equation (2) (Bautista and Minowa, 2010):

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

Where: *MIE* is the machinery input energy in MJ/ha, *MEC* is the machine energy coefficient at 108.9 MJ/kg (Table 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.

The energy input of each system was also 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 Equation (3) to Equation (6), respectively (Yousefi et al., 2014b).

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

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

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

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

2.4 Estimation of GHG emissions and global warming potentials

The amounts of GHG emissions from inputs in eggplant production per hectare were calculated by using CO_2, N_2O and CH_4 emission coefficients 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.

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

Inputs (unit)	CO2	N20	CH4	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 CO2 equivalent factor	1	298	25	Eggleston et al., 2006

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 one for CO_2, 25 for CH_4 and 298 for N_2O (Eggleston et al.,2006). Other farm inputs such as machinery, plastic and chemical pesticides (insecticide, herbicides and fungicides) were directly multiplied with their GHG emission coefficients presented in Table 3.

Table 3 GHG emission coefficients of agricultural inputs

Inputs (unit)	GHG Coefficient (kg CO_{2eq}/unit)	References
1. Machinery (MJ)	0.071	Dyer and Desjardins, 2006
2. PET Plastic (kg)	2.50	EPA, 2012
3. Chemical pesticides		
Insecticides (kg)	5.10	Nabavi-Pelesaraei et al., 2014
Herbicides (kg)	6.30	Nabavi-Pelesaraei et al., 2014
Fungicides (kg)	3.90	Nabavi-Pelesaraei et al., 2014

The total GWPs (in kg CO_{2eq}) were integrated and determined the GWPs per hectare of eggplant production.

The total emissions of greenhouse gases are determined using Equation (7) (Kramer et al., 1999):

$$GHG\ Effect = \sum GWPi\ x\ Mi \quad (7)$$

Mi is the mass (in kg) of the emission gas. The resulting value is expressed in terms of CO_2 equivalent [kg CO_{2eq}].

In order to determine whether the production of eggplant is a carbon neutral, carbon sequestration or more on carbon emission, the carbon efficiency ratio was calculated using Equation (8).

$$Carbon\ efficiency\ ratio = \frac{Output\ yield\ \ (kg\ C/ha)}{GWP\ (kg\ C/ha)} \quad (8)$$

Where, the output yield was converted to carbon (C) content equivalent. The C content is usually 45% of the total yield (Bolinder et al., 2007). GWP is based on carbon dioxide equivalent, thus, to determine the C content, this amount should be multiplied by the ratio of carbon to carbon dioxide, that is, 12/44 (0.273).

3 Results and discussion

3.1 Input-output energy of eggplant production

As summarized in Table 4, the energy consumption in the production of eggplant was 77, 342.01 MJ/ha. The average yield value of eggplant was 39,645 kg/ha with an equivalent energy output of 233,905.50 MJ/ha. Accordingly, the calculated net energy was 156,563.41 MJ/ha.

Table 4 Energy input and outputof eggplant production; Philippines; 2015

Inputs and Output		Total energy equivalent (MJ/ha)	Energy Share (%)
A.	**Inputs**		
1.	Diesel	31,965.76	41.33
2.	Machinery	86.50	0.11
3.	Animal power	0.00	0.00
4.	Human labor	8,708.28	11.26
5.	Chemical fertilizers	23,421.40	30.28
	Nitrogen-N	20,852.70	29.96
	Phosphorous-P_2O_5	1,513.80	1.96
	Potassium-K_2O	1,054.90	1.36
6.	Organic fertilizers	45.00	0.06
7.	Chemical pesticides	2,530.00	3.27
8.	Irrigation water	6,390.72	
9.	Plastic (PET)	4,194.44	5.52
	Total Input	77,342.09	100.00
B.	**Output**		
Eggplant (Fresh)		233,905.50	
C.	**Net Energy**	156,563.41	

The percentage sharing of energy associated with inputs is also presented in Table 4. It is evident that majority of the total energy input were contributed by diesel fuel (41.33%) followed by chemical fertilizers at 30.28%. Diesel fuel was used for operating tractors during land preparation, water pumping systems for irrigation and the delivery of eggplant from farm to market. Among the chemical fertilizers, nitrogen played the highest share of 29.96% of the total energy utilized. Similar results have been reported that diesel fuel and fertilizers were the most intensive energy inputs in agricultural crop production (Nabavi-Pelesaraei et al., 2013b; Erdal et al., 2007; Mobtaker et al., 2010; Kizilaslan, 2009).

3.2 Energy use per operation in eggplant production

Considering the energy employed for each operation in the agricultural production system of eggplant as presented in Table 5, preharvest operation consumed more of energy at 59, 673.92 MJ/ha with 77.16% share than postharvest operation at 17,668.18 MJ/ha with 22.84% share in the total input energy for eggplant production. Among the operations, the irrigation provided the highest share of energy (35.57%) followed by the application of fertilizers (30.59%). The results were mainly influenced by the excessive use of nitrogen during the fertilizer application and diesel fuel during irrigation.

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

Operation		Total energy equivalent (MJ/ha)	Energy Share (%)
	Preharvest	***59, 673.92***	***77.16***
1.	Land preparation	2.874.00	3.72
2.	Seedling production	78.88	0.10
3.	Transplanting	188.16	0.24
4.	Irrigation	27,508.20	35.79
5.	Fertilizer application	23,672.28	30.59
6.	Pesticide application	4,725.20	6.11
7.	Manual weeding	627.20	0.81
Postharvest		***17,668.18***	***22.84***
8.	Harvesting	2,2646.00	3.42
9.	In-field hauling	49.00	0.06
10.	Sorting and packing	6,252.44	8.08
11.	Transport to market	8,720.74	11.29
Total Input		**77,342.09**	**100.00**

3.3 Energy indicators in eggplant production

Energy indicators such as energy ratio, energy productivity, specific energy and net energy gain of the eggplant production are presented 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 crop production.

Table 6 Indicators of energy use in eggplant production

Indicators	Unit	Quantity
Inputs Energy	MJ/ha	77,342.09
Output Energy	MJ/ha	233,905.50
Energy ratio	-	3.02
Energy Productivity	kg/MJ	0.51
Specific Energy	MJ/kg	1.97
Net Energy	MJ/ha	156,563.41

The energy ratio for eggplant production was found to be 3.02, indicating that the output energy of eggplant is obtained 3.02 times greater than the total input energy used in the production process. This also implied that the energy consumed in eggplant production can be replenished by 3.02 times because of high energy output generated from harvested eggplant.

The value of energy ratios have been reported for various crops such as 3.02 for canola (Mousavi-Avval et al., 2011), 0.017 and 0.33 for greenhouse and open-field cucumber respectively (Yousefi et al., 2012), 2.8 for greenhouse vegetable in Turkey (Ozkan et al., 2004), 1.71 for potato (Pishgar-Komleh et al., 2012), 2.67 for corn (Yousefi et al., 2014a), 0.45 for wheat (Khoshnevisan et al., 2012) and 1.58 for kiwi-fruit in Iran (Mohammadi et al., 2010). The calculated specific energy value of eggplant production was 1.97 MJ/kg while the energy productivity was 0.51 kg/MJ. This means that 1.97 MJ input energy is needed to produce one kilogram of eggplant or 0.51 kg of eggplant is produced per unit (MJ) input energy.

3.4 Energy forms in eggplant production

The input energy classification utilized for eggplant production can be distributed into direct (DE) and indirect (IDE) or renewable (RE) and non-renewable (NRE) forms of energy as presented in Table 7. Apparently, direct energy share of 60.93% surpassed the indirect energy share of 49.07% in the total input energy consumption for eggplant production. This was attributed to the use of inputs such as diesel fuel and human labor in the production.

Table 7 Total energy inputs classified into direct, indirect, renewable and non-renewable forms used in eggplant production, Pangasinan and Quezon, Philippines; 2015

Energy Form	Quantity (MJ/ha)	Share (%)
Direct Energy [a]	47, 109.76	60.93
Indirect Energy [b]	30,232.33	39.07
Renewable Energy [c]	15, 144.00	19.58
Non-renewable Energy [d]	62,198.09	80.42
Total Energy Input	77, 342.09	100.00

Note: [a]Includes human labor, animal labor, diesel, irrigation water

[b]Includes machinery, chemical fertilizers, chemical pesticides, organic fertilizer, plastic

[c]Includes human labor, animal labor, organic fertilizer, irrigation water

[d]Includes diesel, chemical fertilizers, chemical pesticides, machinery, plastic

Bulk of the total input energy was non-renewable energy at 80.42% while the remaining renewable energy input was 19.58%. The results implied that the level of reliance to non-renewable form of energy was generally high, indicating further that the eggplant production depends mostly on fossil resources. Similar trends where the ratio of DE is higher than IDE and the rate of NRE is greater than RE in the production of different agricultural crops have been reported (Mobtaker et al., 2010; Erdal et al., 2007). The introduction of organic farming and the use of renewable input resources are encouraged to minimize the usage of fossil resources and promote sustainable agriculture.

3.5 GHGs emission and GWPs in eggplant production

The amount of greenhouse gas emissions with the use of machinery and chemical inputs in eggplant production per hectare was calculated and tabulated in Table 8. The total GWP of eggplant production was 5,843.35 kg CO_{2eq}/ha. This indicated that every one hectare production of eggplant would lead to GWP generation of 5,843.35 kg CO_{2eq}. Highest share of GWPs was observed for diesel fuel (41.55%), followed by plastic (PET) used for packaging of eggplant (39.01%) and then chemical fertilizers (17.15%). Among the chemical fertilizers, nitrogen significantly provided the highest share of 14.63%. Generally, the results indicated that the use of more NRE resources such as diesel, petroleum based plastics and chemical fertilizers would incur more energy inputs that would lead to more emission of greenhouse gases and global warming potential.

Table 8 Greenhouse gas emission from agricultural inputs used in eggplant production; Pangasinan and Quezon, Philippines; 2015

Inputs	GHG Emission (kg CO_{2eq}/ha)	GHG Emission Share (%)
Machinery	6.14	0.11
Diesel fuel	2,427.85	41.55
Plastic (PET)	2,279.59	39.01
Chemical Fertilizers	1,002.27	17.15
(a) Nitrogen (N)	854.78	14.63
(b) Phosphorous (P2O5)	91.43	1.56
(c) Potassium (K2O)	56.05	0.96
Chemical Pesticides		
(a) Insecticides	127.50	2.18
Total GHG emission	5,843.35	100.00

3.6 Input-output carbon and carbon efficiency (ratio) in eggplant production

Eggplant in fresh form was the output yield considered in the input-output carbon analysis. The average production yield of eggplant was 39,645kg/ha to give a total carbon output of 17, 840.25 kg C/ha (Table 9). The total input carbon related with the application of agricultural inputs was 1,593.65 kg C/ha. Accordingly, the carbon ratio (sustainability index) in the production of eggplant is 11.18. This carbon efficiency ratio was related to the high yield of eggplant in the study areas. This implies that the existing cultural practices of eggplant production in the Philippines, is a carbon neutral process because it does not emit carbon to the atmosphere beyond the carbon output produced from the production of eggplant itself. Moreover, input carbon was exceeded 11 times by the output carbon, indicating that eggplants can also be one of the crops for carbon sequestration.

Table 9 Output-input carbon and carbon efficiency (sustainability index) of eggplant production, Pangasinan and Quezon, Philippines; 2015)

Indicators	Value	Unit
Input Carbon	1,593.64	kg C/ha
Output Carbon	17,840.25	kg C/ha
Net Carbon	16,246.61	kg C/ha
Carbon efficiency (ratio)	11.18	-

The use of fossil resources including diesel, plastics and chemical fertilizers and pesticides are among the inputs affecting the carbon efficiency ratio in eggplant production. Thus, it is necessary to always correct the pattern of use of chemical inputs and non-renewable energy resources to maintain the sustainability of eggplant production. The use of renewable sources (composts or organic fertilizers, environment-friendly biological control agent for pest and diseases, biodiesel, etc), utilization of new machineries for cultivation, more efficient pumps for extracting irrigation water, application of mulches to conserve soil moisture and prevent the growth of weeds thereby reducing irrigation frequency can lead to cultivation/production of eggplant with less environmental carbon footprints.

4 Conclusions and recommendations

Overall, the production of eggplant using the present cultural practices is carbon neutral or its outputs can store or sequester more C than what was generated by the inputs used in production.

The sustainability of eggplant production can be maintained by checking the use of chemical inputs and non-renewable energy resources. Crop rotation with nitrogen stabilizer plants such as leguminous plants must be considered to reduce the use of inorganic N fertilizer. Organic fertilizer or green manure instead of chemical fertilizer should be considered to minimize the high rate of non-renewable energy utilization and reduce the amount of GHGs emissions. The use of biodiesel for agricultural machines and improved or new machineries for land preparation, water pumping for irrigation and transportation must also be considered to reduce the amount of fossil fuel consumption. Cultural practices such as mulching using organic mulching materials can also reduce diesel fuel needed in irrigation and reduce the use of chemical herbicides/weedicides. The use of bioplastics which have lower carbon footprints should also be explored as packaging material instead of the polyethylene bags.

Agricultural training of farmer-producers on good agricultural practices (GAP), production of organic fertilizers from biological crop wastes and provision of adequate financial incentives for organically-produced eggplant could also facilitate the change towards a more environment-friendly production practices.

References

Asgharipour, M.R., F. Mondani, and S. Riahinia. 2012. Energy use efficiency and economic analysis of sugar beet production system in Iran: a case study in Khorasan Razavi province. *Energy*, 44 (1):1078–1084.

Bautista, E.G., and T. Minowa. 2010. Analysis of the energy for different rice production systems in the Philippines. *The Philippine Agricultural Scientist*, 93(3):322-333.

Bolinder, M.A., H.H. Janzen, E.G. Gregorich, D.A. Angers, and A.J. VandenBygaart. 2007. An approach for estimating net primary productivity and annual carbon inputs to soil for common agricultural crops in Canada. *Agriculture, Ecosystems and Environment*, 118 (1-4): 29-42.

BAS-Bureau of Agricultural Statistics. 2014. Production volume of eggplant. Philippines: Department of Agriculture.

Doering III, O. C. 1980. Accounting for energy in farm machinery and buildings. In Pimentel, D. Handbook of energy utilization in agriculture. Boca Raton: CRC Press, Inc., 1, 9-14.

Demircan, V., K. Ekinci, H.M. Keener, D. Akbolat, and C. Ekinci.2006. Energy and economic analysis of sweet cherry production in Turkey: A case study from Isparta province. *Energy Conversion and Management*, 47(13-14):1761-1769.

Dyer, J.A., and R.L. Desjardins. 2006. Carbon dioxide emissions associated with the manufacturing of tractors and farm machinery in Canada. *Biosyst Eng*, 93(1):107-118.

Eggleston, S., L. Buendia, K. Miwa, T. Ngara, and K. Tanabe. 2006. Intergovernmental Panel on Climate Change. *IPCC Guidelines for National Greenhouse Gas Inventories.*, eds.

EPA-Environmental Protection Agency.2012.Waste Reduction Model (WARM). Plastics. Accessed July 17, 2015 Available at: http://www.epa.gov/climatechange/wvcd/waste/ downloads/Plastic.pdf.

Erdal, G., K. Esengun, H. Erdal, and O. Gunduz. 2007. Energy use and economic analysis of sugar beet production in Tokat province of Turkey. *Energy*, 32(1):35–41.

Esengun, K., O. Gunduz, and G.Erdal.2006. Input–output energy analysis in dry apricot production of Turkey. *Energy Conversion Management*, 48(2):592–598.

Fluck, R.C. 1985. Energy sequestered in repair and maintenance of agricultural machinery. *Transactions of the ASAE*, 28(3):734-744.

FAO-Food and Agriculture Organization.2012.World Production Volume of Eggplant.

Hatirli, S. A., B. Ozkan, and C. Fert. 2005. An econometric analysis of input energy/output in Turkish agriculture. *Renewable and Sustainable Energy Reviews*, 9(6):608–623.

IPCC-Intergovernmental Panel on Climate Change. 2007. Climate change, impacts adaptation and vulnerability. In *Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change*, p. 976. Cambridge, UK: Cambridge University press.

Karakaya, A., and M.Ozilgen.2011. Energy utilization and carbon dioxide emission in the fresh, paste, whole-peeled and juiced tomato production processes. *Energy*, 36(8):5101-5110.

Kitani, O. 1999. Energy and biomass engineering. CIGR handbook of agricultural engineering. vol. 5. St Joseph, MI: ASAE Publication.

Kizilaslan, H.2009. Input–output energy analysis of cherries production in Tokat Province of Turkey. *Applied Energy*, 86(7-8):1354-1358.

Khoshnevisan, B., S. Rafiee, M. Omid, M. Yousefi, and M. Movahedi. 2013. Modeling of energy consumption and GHG (greenhouse gas) emissions in wheat production in Esfahan province of Iran using artificial neural networks. *Energy*, 52(1):333–338.

Kramer, K. J.,H. C. Moll, and S.Nonhebel.1999. Total greenhouse gas emissions related to the Dutch crop production system. *Agriculture, Ecosystems and Environment*, 72(1): 9–16.

Mobtaker, H.G., A. Keyhani, A. Mohammadi, S. Rafiee, and A. Akram. 2010. Sensitivity analysis of energy inputs for barley production in Hamedan Province of Iran. *Agriculture, Ecosystems and Environment*, 137(3-4):367–372.

Mohammadi, A. and M. Omid. 2010. Economic analysis and relation between input energy and yield of greenhouse cucumber production in Iran. *Applied Energy*, 87(1):191–196.

Mousavi-Avval, S.H., S. Rafiee, A. Jafari, and A. Mohammadi. 2011. Energy flow modeling and sensitivity analysis of inputs for canola production in Iran. *Journal of Cleaner Production*, 19(13):1464-1470.

Nabavi-Pelesaraei, A., R. Abdi, S. Rafiee, and K. Taromi. 2014. Applying data envelopment analysis approach to improve energy efficiency and reduce greenhouse gas emission of rice production. *Engineering in Agriculture, Environment and Food*, 7(4):155-162.

Nabavi-Pelesaraei, A., R. Abdi, S. Rafiee, and H.G. Mobtaker. 2013a. Optimization of energy required and greenhouse gas emissions analysis for orange producers using data envelopment analysis approach. *Journal of Cleaner Production*, 65:311-317.

Nabavi-Pelesaraei, A., A. Sadeghzadeh, M. H. Payman, and H.G. Mobtaker. 2013b. Energy flow modeling, economic and sensitivity analysis of eggplant production in Guilan province of Iran. *International Journal Agriculture and Crop Sciences*, 5(24):3006-3015.

Nemecek, T., D. Dubois, O. Huguenin-Elie, and G. Gaillard. 2011. Life cycle assessment of Swiss farming systems: Integrated and organic farming. *Agricultural Systems*,104(3): 217-232.

Ozkan, B., C. Fert, and C. F. Karadeniz. 2007. Energy and cost analysis for greenhouse and open- field grape production. *Energy*, 32(8):1500-1504.

Ozkan, B., H. Alcaoz, and C. Fert. 2004a. Input-output energy analysis in Turkish agriculture. *Renewable Energy*, 29(1):39-51.

Pahlavan, R., M. Omid, S. Rafiee, and S. H. Mousavi-Avval. 2012. Optimization of energy consumption for rose production in Iran. *Energy for Sustainable Development*, 16(2):236-241.

Pimentel, D.1979. Energy in food production. Department of Entomology and Limnology. Cornell University, Ithaca, New York, USA. URL: http:// www.jtor.org/

Pimentel, D.1992. Energy inputs in production agriculture. In *Energy in World Agriculture*.13-29.Amsterdam: Elsevier Science.

Pishgar-Komleh, S. H., P. Sefeedpari, and S. Rafiee. 2011. Energy and economic analysis of rice production under different farm levels in Guilan province of Iran. *Energy*, 36(10):5824-5831.

Pishgar-Komleh, S. H., M. Ghahderijani, and P. Sefeedpari. 2012. Energy consumption and CO2 emissions analysis of potato production based on different farm size levels in Iran. *Journal of Cleaner Production*, 33:183-191.

Pishgar-Komleh, S. H., M. Omid, and M. D.Heidari.2013. On the study of energy use and GHG (greenhouse gas) emissions in greenhouse cucumber production in Yazd province. *Energy*, 59:63-71.

Soltani, A., M.H. Rajabi, F. Zeinali, and F.Soltani.2013. Energy inputs and greenhouse gases emissions in wheat production in Gorgan, Iran. *Energy*, 50:54-61.

Snyder, C. S., T. W. Bruulsema, T. L. Jensen, and P. E. Fixen. 2009. Review of greenhouse gas emissions from crop production systems and fertilizer management effects. *Agriculture, Ecosystems and Environment*, 133(3-4):247–266.

Tzilivakis, J., D. J. Warner, M. May, K. A. Lewis, and K.Jaggard2005. An assessment of the energy inputs and greenhouse gas emissions in sugar beet (Beta vulgaris) production in the UK. *Agricultural Systems*, 85(2):101–119.

UNEP-United Nations Environmental Program.2009. Converting waste plastics into a resource. 1-51. Available at:http://www.unep.or.jp/Ietc/Publications/spc/WastePlasticsEST_Compendium.pdf. Accessed July 13 2015.

Yousefi, M., F. Darijani, and J.A. Alipour. 2012. Comparing energy flow of greenhouse and open field cucumber production systems in Iran. *African Journal of Agricultural Research*,7(4):624-628.

Yousefi, M., A.M. Damghani, and M. Khoramivafa. 2014a. Energy consumption, greenhouse gas emissions and assessment of sustainability index in corn agroecosystems of Iran. *Science of the Total Environment*, 493: 330-335.

Yousefi, M., M. Khoramivafa, and F. Mondani. 2014b. Integrated evaluation of energy use, greenhouse gas emissions and global warming potential for sugar beet (Beta vulgaris) agroecosystems in Iran. *Atmospheric Environment*, 92:501-505.