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ENVIRONMENTAL ASSESSMENT OF CUCUMBER FARMING USING ENERGY AND GREENHOUSE GAS EMISSION INDEXES

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ABSTRACT

Energy and GHG (greenhouse gas) emissions evaluation is from the most common methods for assessment of environmental status of production activities. In this study energy and GHG balance in the greenhouse cucumber production in Yazd province of Iran were assessed. Data of this study were collected using a face to face questionnaire method from the farmers growing cucumber crops. Study results showed that the average annual crop yield of the greenhouses was 89868.54 kg/ha which demanded an average energy input of 699217.04 MJ/ha. Diesel fuel and electricity were the biggest energy consumers in the farms with shares of 59.31 and 25.58% of total input energy. These two inputs also were the biggest air pollutant with the emissions of 33128.65 and 62309.23 kg CO2-eq per hectare respectively. The results also showed that a quadratic model was the best for modeling the relations between the crop yield and total energy input, GHG per yield and energy intensity; and linear model was the best for modeling relation between yield and energy productivity.

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KEY WORDS

Cucumber farming, Energy indexes, GHG emission, Yield sensitivity

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INTRODUCTION

When we discuss about agriculture, its unwanted effects on the environmental cannot be ignored. Agriculture and energy have a close relationship since agriculture is both consumer and producer of energy in the form of bioenergy [1]. Efficient use of energy is one of the principal requirements of sustainable agriculture. To evaluate the sustainability of agriculture, its energy efficiency must be considered, and major sources of energy waste must be identified and assessed [2]. Direct fossil energy use by agriculture is about 3.0-4.5% of the total energy consumption in the developed countries of the world [3]. On the other hand the indirect energy used for production, formulation, storage and distribution of agricultural inputs and their application with tractorized equipment involves a greet share of total consumed energy in world. This trend in consumption of energy is along with the emissions of CO_2 and other Greenhouse Gases (GHGs) into the atmosphere [4]. Agriculture accounts for one-fifth of the annual increase in anthropogenic greenhouse warming. Agriculture is the main source of non-carbon dioxide GHGs, emitting nearly 60% of nitrous oxide (N_2O) and nearly 50% of methane (CH_4) [5]. If agricultural production is going to significantly increase while also minimizing its impact on future climate change, it is important to understand the current status of energy and GHG budgets and their link with farms outputs. Energy and GHG emission analysis in agricultural production operations results in determining overuse sectors and may act as a platform to improve production processes.

Considering the energy balance of crop production was much debated in the early 1970s when the world energy crisis made people aware from limitation of fossil supply [31]. After that considerable studies have been conducted in energy efficiency of various agricultural productions such as grains [7-9], greenhouse crops [10,11], hay crops [12], fruits [13,14], vegetables [15] etc. While, there are few studies on the topic of gas emissions as result of agricultural in-farm and off-farm activities. Shortages of information about gas emissions in the production processes of agricultural inputs may be one of the most important reasons of this ignorance. However, there are some studies that tried to evaluate and analyze the gas emissions of agricultural activities [16,17,4]. In this study we analyzed the energy and GHG balance in cucumber production and evaluated the sensitivity of energy and GHG criteria to the output yield.

The cucumber (Cucumis sativus) is a widely cultivated plant in the gourd family Cucurbitaceous which include squash and the same genus as the muskmelon. It is a warm-season plant and grows rapidly at 24–29˚C temperatures [35]. China is biggest producer of cucumbers on the planet. Iran is the next big producer of cucumber. In Iran, it was cultivated on 77,951 ha (in field and in greenhouse) and the production was 1715024 tons in 2010 [25]. In 2012 Iran exported more than 188000 tons of cucumber which brought more than 141 million dollars income for Iran. Iran was the fourth largest cucumber exporter after Spain, Mexico and Netherlands. Yazd province with cultivated area of 1003 ha was one of the major Iranian cucumber greenhouse producers with the total production of 300,165 t in 2010 [25].

MATERIALS AND METHODS

Data collection

Data used in this study were obtained by using a face-to-face questionnaire method from 32 farmers growing single crop of cucumber in greenhouses in Taft county of Yazd province, Iran during 2011-2012. These farmers were selected randomized according simple random sampling method. Yazd province, with area of 7215 ha, is located in the center of Iran within 29˚48́ to 33˚30́ north latitude and 52˚45́ to 56˚30́ east longitude. The study region climate is hot and relatively dry and the average annual rainfall is reported to be 50- 350 mm. In the studied province the greenhouse cucumber is raised only in the cold seasons of year. The supplementary data on the farms were obtained from Ministry of Jihad-e-Agriculture of Iran. The sample size was calculated according equation 1 as described by Ghasemi Mobtaker et al., [18]:

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

where n is required sample size, N is the number of holdings in target population (102 in this study), s is standard deviation (calculated as 0.173), d is acceptable error (permissible error was chosen as 5%) and t is confidence limit (1.96 in the case of 95% reliability).

Energy calculation

Farm inputs and outputs can be expressed in terms of energy equivalents. The total energy use per unit of activity can be expressed in terms of MJ/ha, indicating overall energy consumption. In this study energy budget was calculated based on a mix of actual data from farms and energy coefficients. The energy equivalents for different inputs and outputs used in energy budget calculation are shown in column 3 of **Table– 1**. The energy cost of inputs and practices were adapted from different sources of estimations that best fit Iran conditions. We calculated energy intensity and energy productivity as indexes of energy use efficiency using Equations 1 and 2 [19]:

$$\text{Energy productivity} = \frac{\text{Output yield (kg ha}^{-1})}{\text{Energy input (kg ha}^{-1})} \qquad (2)$$

$$\text{Energy intencity} = \frac{\text{Energy input (Mj ha}^{-1})}{\text{Cucumber output (kg ha}^{-1})} \qquad (3)$$

The input energy is also classified into direct and indirect; and renewable and non-renewable forms. The indirect energy included energy embodied in chemicals, manure, machine and equipment; while the direct energy includes human power, fuel and electricity in the production process. On the other hand, non-renewable energy includes diesel, electricity, pesticides and fertilizers; while renewable energy consists of human and manure fertilizer [20].

GHGs emission

Production, storage and application of inputs in agricultural farms invoke combustion of fuels, which results in CO_2 and other GHGs emission. Global Warming Potential (GWP) is an index presenting the impact of gaseous gases on the atmosphere's capacity of absorbing infrared radiation, which contributes to the global greenhouse gas effect. The GWP is expressed in kg CO_2 equivalent (CO_2-eq), which is taken to be 1 for CO_2, 296 for N_2O and 23 for CH_4 (IPCC 2006). Conversion coefficients CO_2-eq is calculated for each farm input based on its GHGs emissions during its production or/and consumption and can be expressed in kg CO_2-eq per weigh of input. Total CO_2-eq index is calculated by the sum of CO_2-eq of all farms inputs in terms of kg/ha [21].
Used conversion coefficients in this study are presented in column 5 of **Table–1**. We used conversion coefficients for different fuels and electricity for Iran calculated by Sami et al., [21]. N fertilizer has two sources of GHGs emission; off-farm emissions which involve GHGs emissions from production, packaging and transporting of fertilizers and on-farm emissions which involve

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emissions from soil denitrification and nitrification processes in the field after distribution of fertilizers. Precise measurement of N_2O emissions from soil denitrification and nitrification processes is difficult since it depends on many complex interactions taking place in the soil, and can considerably vary depending on temperature, moisture, available N, organic matter, soil aeration, pH and so on. Nevertheless, direct N_2O emissions have been shown to relate to N inputs. Therefore, amounts of N_2O emissions are often calculated using an emission factor that represents the percentage of any N applied that emits in the form of N_2O [22]. According to IPCC [23], the amount of C lost via harvested crops is considered to be replaced by C uptake in the following crop and there is no significant long-term accumulation of C in crops products. Therefore, we did not take into account this carbon cycle [21]. We used two indexes including GHG per yield and GHG per hectare to present the GHG emissions status of farms

Table:1. Coefficients of CO_2-eq and energy of inputs in farms

Item	Unit/ha	Energy equivalent (MJ/unit)	References	CO_2-eq coefficient (kg/unit)	References
N fertilizer	kg	78.10	[32]	3.97 (off-farm) + 2.96 (on-farm)	[21]
P fertilizer	kg	17.40	[32]	1.30	[34]
K fertilizer	kg	13.70	[32]	0.71	[34]
Micro fertilizer	kg	8.80	[32]	0.66	[34]
Manure	ton	303.00	[32]	27.50	[4]
Diesel fuel	lit	41.06	[21]	3.28	[21]
Electricity*	kWh	12.00	[32]	4.18	[21]
Fungicides	kg or l	210.00	[33]	14.49	[21]
Insecticides	kg or l	101.20	[32]	29.00	[34]
Human labour	h	2.20	[6]	-	-
Cucumber seed	kg	1.00	[25]	-	-

*the data for electricity is for Iran distribution network electricity which is combined of thermal energy sources and hydroelectric energy sources

RESULTS

The amount of inputs used in the production of cucumber was specified in order to calculate energy and CO_2 equivalences in the study. Inputs in cucumber production were: human power, diesel fuel, fertilizers, pesticides, electricity and seed. The output was considered cucumber yield. The related energies of different inputs used in the studied greenhouses are shown in **Table−2** (column 3). As it can be seen, the highest energy input belonged to diesel fuel with a share of 59.31% of total energy input (414,714.13 MJ/ha). The diesel was mostly used as the fuel for greenhouse heaters. This high rate of diesel consumption in the greenhouses of the studied region could be attributed to cold weather conditions of growing seasons on the one hand and low thermal efficiency of greenhouses buildings on the other. Reducing heat exchange between outside and inside of greenhouses by using double layer plastic film plus internal thermal blanket can decrease the amount of diesel fuel consumption in greenhouses [25]. Fuel for heating was reported as the biggest energy consumer in the greenhouses by many researchers. Taki et al., [26], Heidari and Omid [24], and Pishgar-Komleh et al., [25] reported the fuel as the most important input energy in their studies with proportions of 40, 54 and 68% of total input energy respectively. The second most demanding energy input for cucumber production in the studied region was electricity (25.58%). Electricity was mostly used for air conditioners to circulate and exchange air and also for water pumping and spraying. Use of more efficient fans and water pumps may considerably decrease the consumed electricity in the greenhouses. this result was in agreement with the results of Pishgar-Komleh et al., [25] who reported the electricity as second most important energy input in greenhouse cucumber farming. Shares of other inputs in the total energy input were insignificant. Least energy demanding inputs were micro fertilizers and seed (with shares of 0.02 and 0.001 respectively).

The share and amount of GHG emitted by each input in cucumber cultivation are shown in columns 5 and 6 of **Table−2**. Electricity in the farms was the dominant source of GHG emissions with a share of 61.60% of total CO_2-eq emissions (62309.23 kg/ha). After electricity the diesel fuel had the highest share (32.75%). Other than electricity and fuel other inputs had ignorable shares of total GHG emissions in the studied farms. Fertilizers with a share of 5.31% of total CO2-eq emissions were ranked as the third air pollutant in terms of GHG emission. Nitrogen and manure were dominant sources of GHG emissions among fertilizers and almost 43.31% of total CO_2-eq emissions from fertilizer use and 2.30% of total CO_2-eq emissions from farming systems belonged to each of them.

Table: 2. Input and outputs of farms and their related indexes in terms of energy

Item	Quantity of input used per hectare (unit/ha)	Input energy (MJ/ha)	%	CO2 equivalent (kg/ha)	%
Labor	17063.00	37538.60	5.37	0.00	0.00
Diesel fuel	10100.20	414714.13	59.31	33128.65	32.75
Pesticides	-	3813.50	0.55	346.40	0.34
Insecticide	4.13	417.47	0.06	119.63	0.12
Fungicide	16.17	3396.03	0.49	226.77	0.22
Fertilizers	-	64271.96	9.19	5369.10	5.31
Manure	84621.48	25640.31	3.67	2327.09	2.30
Nitrogen	335.18	26177.61	3.74	2322.80	2.30
Potassium	673.87	9232.08	1.32	478.45	0.47
Phosphor	177.79	3093.54	0.44	231.13	0.23
Others	15.08	128.42	0.02	9.63	0.01
Electricity	14906.52	178878.18	25.58	62309.23	61.60
Seed	0.07	0.67	0.00	0.00	0.00

Calculated farm indexes are reflected in **Table–3**. The average annual crop yield of the greenhouses was estimated as 89868.54 kg/ha which demanded an average energy input of 699,217.04 MJ/ha. Pashaee et al., [27] estimated the total energy input for greenhouse tomato production in Kermanshah Province of Iran at 123,130 MJ/ha. In another study conducted by Ozkan et al., [28], the total energy inputs for greenhouses produced cucumber in any one period of plant cultivation were reported to be 134,771.3 MJ/ha. Energy productivity of farms was 0.13 kg/MJ. This means that 0.13 kg of output was obtained per unit of input energy. This energy productivity rate is in ranges of other similar reports for greenhouse crops (e.g. 0.11, 0.25 and 0.12 kg/MJ by Pahlavan et al., [15], Salami et al., [29] and Pishgar-Komleh et al., [25]). The average energy intensity of the studied farms was 9.66 MJ/kg. This index shows that 9.66 MJ of energy was used for production of one kilogram of cucumber. The total energy input of studied farms could be classified as direct (90.26%), indirect (9.74%) or renewable energy (9.04%) and non-renewable energy (90.96%). In the several past studies the ratio of direct energy was reported higher than that of indirect energy, and the ratio of non-renewable energy greater than that for renewable energy [e.g. 12,14,1]. In the process of cucumber cultivation, as it can be seen in the **Table–2**, 101,153.38 kg CO_2-eq per hectare and 1.42 kg per weight of crop was emitted.

Table: 3. Calculated indexes of the farms

Calculated indexes	Unit	Quantity	%
Total output yield	kg/ha	89868.54	-
Energy intensity	MJ/kg	9.66	-
Energy productivity	kg/MJ	0.13	-
Indirect energy	MJ/ha	68086.12	9.74
Direct energy	MJ/ha	631130.92	90.26
Renewable energy	MJ/ha	63179.58	9.04
Nonrenewable energy	MJ/ha	636037.46	90.96
Total energy input	MJ/ha	699217.04	100.00
GHG per output	kg/ kg	1.42	
GHG per hectare	kg /ha	101153.38	

In this study we also evaluated the relations between the output yield and total input energy, GHG per yield, energy intensity and energy productivity. The plots of observed values of the total crop yield versus calculated indexes are presented in **Figures–1 and –4**. The regression coefficients in relationship between parameters and the corresponding R^2 values are given in these Figures. The coefficient of determination (R^2) between yield and total input energy, GHG per yield, energy intensity and energy productivity were 0.29, 0.75, 0.92 and 0.83, respectively. The best relationship between crop yield and total energy input, GHG per yield and energy intensity

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were expressed in the form of second degree polynomial regression. Quadratic model for prediction of crop yield using total input energy was also suggested by Canakci and Akinci [30] or cucumber in Turkey. **Figure−1** shows that the crop yield in greenhouses increased in response to the total input energy at first, but with more increase in the input energy, yield showed a decrease. This shows that the highest energy efficiency provided with the use of special rate of input energy and more increase in the input energy is along with the waste of energy. However obtained coefficient of determination in this figure is low and therefore the presented polynomial regression cannot be suggested as a reliable model for estimation but the plot provides a total overview on the relationship of crop yield and total input energy**.** **Figures−2 and -3** show that the least energy consumption and GHG emissions per weight of crop yield was obtained somewhere between 130000- 140000 kg/ha of output yield production. The best relationship between crop yield and energy productivity was expressed as linear regression **[Figure−4]**. This shows that the energy productivity in greenhouses increased by increasing in the crop yield.

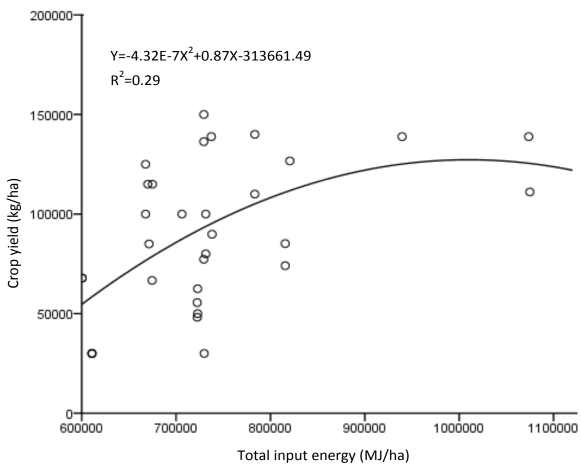


Fig:1. Crop yield versus total energy input

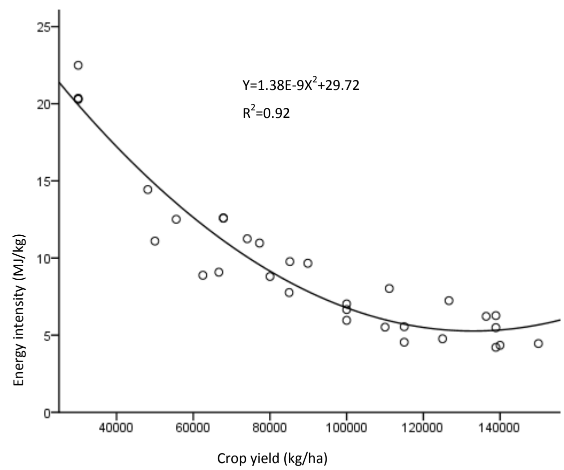
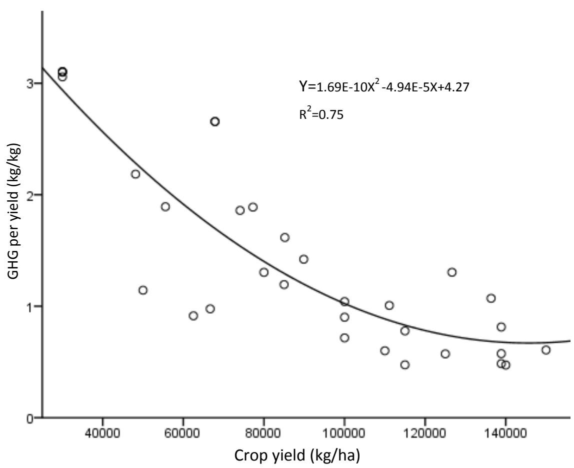


Fig:2. Energy intensity versus crop yield



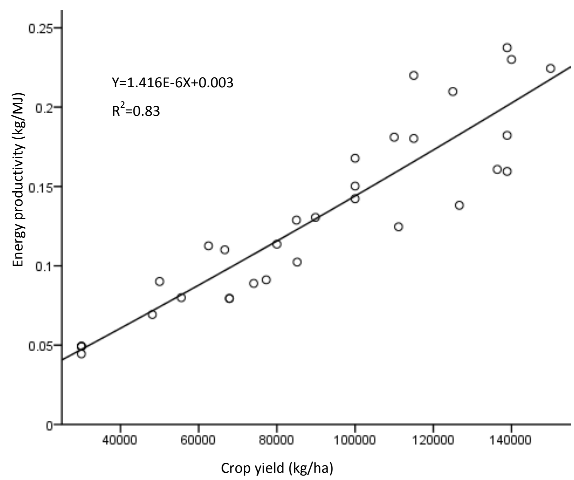


Fig:3. GHG per yield versus crop yield **Fig:4. Energy productivity versus crop yield**

CONCLUSION

The present study evaluated the energy and GHG balance of greenhouse cucumber in Yazd province of Iran. The results indicated that fuel and electricity were the most important environmental pollutant in terms of energy consumption and GHG emission. The cucumber production was very dependent on direct and non renewable energies so that the share of direct energy from total input energy was very greater than indirect energy and the share of non renewable energy was also very greater than renewable energy. Assessing relations between crop

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yield and calculated environmental indexes showed that the highest efficiency of energy and the lowest GHG emissions were achieved in the specific rate of yield production per hectare.

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CONFLICT OF INTEREST

The authors declare having no competing interests

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