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Integrated evaluation of energy use, greenhouse gas emissions and global warming potential for sugar beet (*Beta vulgaris*) agroecosystems in Iran

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HIGHLIGHTS

- Increasing use of chemical inputs leaded to increased input energy with decreasing energy efficiency.
- CO_2, N_2O and CH_4 emissions in sugar beet agroecosystems were 2668.35, 22.92 and 3.49 kg ha^{-1}, respectively.
- Total global warming potential (GWPs) in this agroecosystems was 9847.77 kg CO_2eq ha^{-1}.
- High consumption of fossil fuels and chemical fertilizers increased greenhouse gas emissions.
- Increase in greenhouse gas emissions leaded to global warming potential and environmental crises by atmospheric pollutions.

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ABSTRACT

The main aim of this study was to determine and discuss the aggregate of energy use and greenhouse gas emission (CO_2, N_2O, and CH_4) for sugar beet agroecosystems in western of Iran. For this propose data was collected by using questionnaires and face to face interview with 50 farmers. Results showed that total inputs and output energy were 49517.2 and 1095360.0 MJ ha^{-1}, respectively. Energy use efficiency was 22.12. Total CO_2, N_2O and CH_4 emissions due to chemical inputs were 2668.35, 22.92 and 3.49 kg, respectively. In sugar beet farms total global warming potential (GWPs) was 9847.77 kg CO_2eq ha^{-1}. In terms of CO_2 equivalents, 27% of the GWP_s come from CO_2, 72% from N_2O, and 1% from CH_4. In this research input and output carbon were 29340.0 and 2678.6 kg C ha^{-1}, respectively. Hence, carbon efficiency ratio was 10.95.

1. Introduction

Sugar beet is mainly used for human food, livestock feed and material on industry. Sugar content of sugar beet is about 25% higher than that found in sugar cane (Erdal et al., 2007). Sugar beet is the most widely grown crop in the Iran with 1,829,300 tons in a cropping area of 53951 ha (Ministry of Jihad-e-Agriculture of Iran, 2012).

Consistent with the development of agricultural production systems and move towards modernization in this sector increased dependence of the energy resource. Energy consumption in agriculture has increased year by year while more intensive energy use has led to some important human health and environmental problems such as greenhouse gas emissions and global warming. Therefore, it is necessary to reduce fossil energy inputs in agricultural systems. It would help to reduce agricultural carbon dioxide emissions (Ghorbani et al., 2011). Input energies are consumed very much in modern agricultural systems in compared to traditional agriculture systems, but energy use efficiently has been redacting in response to ineffective use of input energy. However, increased input energy use in order to obtain maximum yields may not bring maximum profits due to increasing production costs (Erdal et al., 2007).

Besides the energy consumption, greenhouse gas (GHG) emission and global warming potential (GWP) issues are also critical in the agricultural production systems in recent twenty years (Khoshnevisan et al., 2013a,b). Gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) produced as a result of agricultural activities, enhance the natural greenhouse effect. Agriculture contributes significantly to atmospheric GHG emissions, with 14% of the global net CO_2 emissions coming from this sector (IPCC, 2007).

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GHG emission estimation in agricultural production systems has been considered by several authors. Kramer et al. (1999) calculated the CO_2, CH_4 and N_2O emissions of Dutch agricultural crop production by using LCA (Life Cycle Assessment) approach. They determined the total GHG emissions per physical unit of agricultural crop. Ho (2011) calculated GHG emissions of wheat production. The total emission was found to be 2963000 kg CO_2 ha^{-1}, where fertilizer had the highest GHG emission (with share of 89%). Karakaya and Ozilgen (2011) determined the energy utilization and the CO_2 emission during the production of fresh, peeled, diced and juiced tomatoes. The energy use of fresh tomato production systems was calculated as 2412.8 MJ t^{-1} while the CO_2 emission was 189.4 kg CO_2 t^{-1}. Tzilivakis et al. (2005) assessed the energy inputs and GHG emissions in sugar beet production in the UK. They reported that the average GWP of 0.024 t CO_2eq per tonne of clean beet harvested, equivalent to 0.0062 t CO_2eq (CO_2 equivalent) per GJ output.

Although, there is a few works on energy use and greenhouse gas emissions in sugar beet production, there is even less data on energy use and CO_2, N_2O, and CH_4 gas emission analysis and carbon use efficiency as important industrial crops. Thus, the objectives of this study were (i) to analyze the output–input energy in sugar beet production systems, (ii) to calculate the total gas emission such as CO_2, N_2O and CH_4, (iii) to determine GWP per unit of chemical input and output and (iv) to assess carbon efficiency ratio for sugar beet production systems in western of Iran that can be affective to reach sustainable management of agroecosystems.

2. Materials and methods

This study was carried in atom 2012 in Kermanshah province (33° 4′ and 35° 17′ N and 45° 25′ and 48° 6′ E), western of Iran. For this investigation data was collected from 50 sugar beet farms by using a face to face questionnaire. Other information was collected from Ministry of Jihad-e-Agriculture of Iran (MAJ) (2012). Total energy input and output in sugar beet production systems were collected by using questionnaires and data analysis. Basic information on energy inputs and sugar beet yield were entered into Excel spreadsheets and then energy forms were calculated according Table 1. Finally energy use efficiency, energy productivity and net energy were determined applying standard Eqs (1)–(3) (Yousefi and Mohammadi, 2011).

$$\text{Energy use efficiency} = \left[\text{output energy}\left(\text{MJ ha}^{-1}\right)\right] \Big/ \times \left[\text{input energy}\left(\text{MJ ha}^{-1}\right)\right] \tag{1}$$

Table 1
Energy equivalents of input and output in sugar beet production systems.

Inputs and output	Unit	Energy equivalents	Reference
A. Inputs			
1. Human labor	H	1.96	(Yousefi and Mohammadi, 2011)
2. Machinery	H	62.70	(Samavatean et al., 2010)
3. Diesel fuel	L	51.33	(Samavatean et al., 2010)
4. Chemical fertilizer	kg		
(a) Nitrogen		66.14	(Erdal et al., 2007)
(b) Phosphate (P_2O_5)		12.44	(Erdal et al., 2007)
5. Farmyard manure	kg	0.30	(Yousefi and Mohammadi, 2011)
6. Chemicals	kg	120.00	(Demircan et al., 2006)
7. Electricity	kwh	3.60	(Rafiee et al., 2010)
8. Water for irrigation	M^3	0.63	(Hatirli et al., 2005)
9. Seed	kg	50.00	(Erdal et al., 2007)
B. Output			
1. Sugar beet yield	kg	16.80	(Erdal et al., 2007)

$$\text{Energy productivity} = \left[\text{Sugar beet yield}\left(\text{kg ha}^{-1}\right)\right] \Big/ \times \left[\text{input energy}\left(\text{MJ ha}^{-1}\right)\right] \tag{2}$$

$$\text{Net Energy} = \left[\text{output energy}\left(\text{MJ ha}^{-1}\right)\right] - \left[\text{input energy}\left(\text{MJ ha}^{-1}\right)\right] \tag{3}$$

The amounts of GHG emissions from chemical inputs in sugar beet production per hectare were calculated by using CO_2, N_2O and CH_4 emissions coefficient of chemical inputs that are shown in Table 2. GHG emissions 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). In this study were calculated the direct emissions form of greenhouse gases of chemical inputs. Due to difficulty in calculating of indirect emissions and also, more effective of direct emissions in GHG and GWP were not calculated indirect emissions.

Each greenhouse gas, i.e. carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) has a GWP, which is the warming influence relative to that of carbon dioxide. The emissions are measured in terms of a reference gas, CO_2 (IPCC, 1995). The GWP of CO_2 (with a time span of 100 years) is 1, of CH_4 is 21, and of N_2O is 310. The total emissions of greenhouse gases are determined as follows (Kramer et al., 1999):

$$\text{Greenhouse effect} = \sum \text{GWP}_i \times M_i \tag{4}$$

M_i is the mass (in kg) of the emission gas. The score is expressed in terms of CO_2 equivalents. In this study carbon efficiency ratio (CER) was calculated using the following equation (5):

$$\text{Carbon efficiency ratio} = \left[\text{output yield}\left(\text{kg C ha}^{-1}\right)\right] \Big/ \times \left[\text{GWP}\left(\text{kg C ha}^{-1}\right)\right] \tag{5}$$

where, the output yield should be converted to carbon equivalent. Usually the carbon content is 45% of the total yield (Bolinder et al., 2007). Moreover, due to the GWP is based on carbon dioxide equivalent, to determine the carbon content this amount should be multiplied on ratio of carbon to carbon dioxide that it is 12/44 (or ~ 0/27).

3. Results and discussion

3.1. Energy input, output and indicators analysis of sugar beet production systems

The inputs used and output in sugar beet production systems, their energy equivalents, and percentages in the total energy input presented in Table 3. The results revealed that total energy input was 49517.2 MJ ha^{-1}. N fertilizer used in sugar beet production

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

Inputs	CO_2	N_2O	CH_4	Reference
1. Diesel (L)	3560.00	0.70	5.20	(Kramer et al., 1999)
2. Nitrogen Fertilizer (kg)	3100.00	0.03	3.70	(Snyder et al., 2009)
3. Phosphate (P_2O_5) (kg)	1000.00	0.02	1.80	(Snyder et al., 2009)
4. Potash (K_2O) (kg)	700.00	0.01	1.00	(Snyder et al., 2009)
5. Electricity (kwh)	61.20	8.82	0.02	(Tzilivakis et al., 2005)
GWP CO_2 equivalence factor	1.00	310.00	21.00	(Tzilivakis et al., 2005)