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Article

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Evaluation of energy input and greenhouse gases emissions from alfalfa production in the Sistan region, Iran



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HIGHLIGHTS

- The total input energy was 313.52 GJ ha⁻¹ where the output was 962.85 GJ ha⁻¹.
- Value of total GHGs emission was estimated at 181,190 kg CO₂e ha⁻¹.
- The highest share of input energy in the production systems belonged to electricity.
- Alfalfa was fairly efficient in terms of energy consumption and GHGs emission.
- In terms of CO₂e, 95.3% of the GWP originate from N₂O, 4.6% from CO₂ and 0.1% from CH₄.

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ABSTRACT

The recognition of forage production methods that maximize energy efficiency and minimize Greenhouse Gases (GHGs) emissions is essential. The aims of this survey were to assess the energy consumption, emissions of GHGs and global warming potential (GWP) of alfalfa production systems in Sistan region, Sistan and Baluchestan province in the South-east of Iran. Data were collected randomly from 110 alfalfa farm using face-to-face questionnaire survey. Energy inputs included chemical fertilizers, diesel fuel, pesticides, seed, machinery and human labor. The results indicated that average total input and output energies in alfalfa production during the entire lifetime of the farm were 313.52 GJ ha⁻¹ and 962.85 GJ ha⁻¹, respectively. The most important energy inputs belonged to electricity (72.5%), followed by diesel fuel (12.3%) and N fertilizer (6.0%). Energy use efficiency and energy productivity were 3.07 and 0.209 kg MJ⁻¹, respectively. Share of direct and indirect energy were 85% and 15%, respectively. Total emissions of CO₂, N₂O and CH₄ in alfalfa farms were 8262.67 kg ha⁻¹, 557.31 kg ha⁻¹ and 7.65 kg ha⁻¹, respectively. Hence, total GWP was 181190 kg CO₂e ha⁻¹ and 2.77 kg of CO₂e kg⁻¹ of dry hay produced. In terms of CO₂e, 95.3% of the GWP originate from N₂O, 4.6% from CO₂ and 0.1% from CH₄. Accordingly, efficient use of energy is essential to reduce the greenhouse gas emissions and environmental impact in alfalfa agroecosystems.

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1. Introduction

Alfalfa (*Medicago sativa* L.) often called queen of the forages, is an important cultivated field crop, originated from northwestern Iran, northeastern Turkey and Turkmenistan. It is cultivated over 618 000 ha in Iran (MAJ, 2011). Sistan and Baluchestan, Kerman and Yazd provinces are the main alfalfa producing zones in central and southeast Iran (Massumi et al., 2012). In Sistan and Baluchestan, where this study has been conducted, the production of alfalfa was near 93 609 ton and the cultivation land area

was approximately 16 800 ha (Department of Agriculture, Zabol, personal communication). Good quality alfalfa has digestible fibers and a range of beneficial vitamins and minerals (Rogers et al., 2014).

There is scientific consensus that global warming results from emission of carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) put one of the major environmental challenges in the future (Pathak and Wassmann, 2007). Agricultural activities and related farming practices contribute a large proportion of the greenhouse gases (GHGs) emissions. It was estimated that agriculture emits about 5.1–6.1 Pg CO₂e year⁻¹, accounting for 10%–12% of global GHGs emissions (Smith et al., 2007). These emissions are mainly in the form of CH₄, mostly from animal production; N₂O, mostly from arable land; and CO₂ mostly from soil carbon changes and energy

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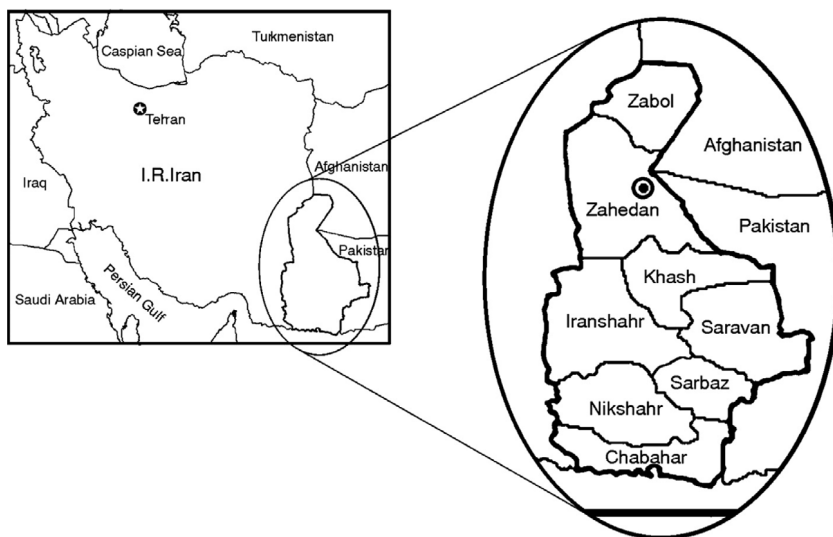


Fig. 1. Geographical situation of Sistan and Baluchistan province, Iran.

use (Smith et al., 2007). As food demand projected to increase in the future, associated GHGs contributions from this sector will also rise (Gilbert, 2011). Minimizing the carbon footprint of agricultural products, i.e., the total GHGs emissions associated with the amount of agricultural products is a challenge (Williams and Wikstrom, 2011).

Production of alfalfa requires intensive use of inputs and therefore has a significant role in the contribution of cropland to global climate change (Camargo et al., 2013). Planting, managing and harvesting of alfalfa using a variety of cultural operations significantly influence the energetics of its production. Although there are an increasing number of studies conducted to evaluate energy balance and GHGs emissions in agricultural crops (Tzivilakis et al., 2005; Khoshnevisan et al., 2013a,b; Ozkan et al., 2007, 2004; Soltani et al., 2013), based on the literature there is no study on the energy consumption and GHGs emissions for alfalfa production in Iran so far.

When assessing the environmental pressures of crop production it is important to differentiate between annual and perennial crops (Mila i Canals et al., 2006). A key difference in energy consumption and GHGs emissions of perennial crop is that some resources are utilized annually while others are existent during the entire lifetime of the farm. Therefore, the objectives of this study were to determine total amount of energy input considering the use of fossil fuels, pesticides, chemical fertilizer, machinery, electricity and labor as well as area-related and product-related GHGs emissions throughout the life of the products in Sistan region of Iran.

2. Materials and methods

2.1. Area of study and data collection

The survey was conducted in Sistan region where is located in Sistan and Baluchistan province, south-east of Iran (Fig. 1). The province is formed of two main parts: the northern part is Sistan and southern part is Baluchistan. The Sistan region (30°5'N–31°28'N and 61°15'E–61°50'E) is one of the driest regions of Iran and famous for “120-day wind of Sistan” during the summer season (Hossenzadeh, 1997). The region has four cities and about 1000 villages, with a population of more than 400 000. The climate of the region is arid with an annual average rainfall of 55 mm and an annual average temperature of 23 °C (Moghaddamnia et al., 2009). The Hirmand River, shared between Iran and Afghanistan, are the

major sources for the agricultural, domestic and industrial sectors in this region (Asgharipour and Azizmoghaddam, 2012).

For this investigation 110 alfalfa production systems were randomly selected for the field questionnaire survey in four cities of studied region. The data was collected by using face to face interviews with farmers. The sample size was calculated using the Neyman method (Yamane, 1967) as is shown below:

$$n = \frac{(\sum N_h S_h)}{N^2 D^2 + \sum N_h S_h^2} \quad (1)$$

where n is the required sample size; N is the number of total population; N_h is the number of population in the h stratification; S_h is the standard deviation in the h stratification, S_h^2 is the variance in the h stratification; D^2 is equal to d^2/z^2 ; d is permitted error ratio deviated from average population $\bar{x} - \bar{X}$ and z is the reliability coefficient (1.96, which represents 95% confidence). The permissible error in the sample population was defined to be 5% within 95% confidence.

2.2. Energy analysis

In accord with other researchers (Mila i Canals and Clemente Polo, 2003; Mila i Canals et al., 2006), not only the one-year field practices were considered, but also all the energy consumption and GHGs emissions relevant to the whole lifetime of the farm. The one-year farm practices were investigated directly on the farms in years 2014, and the life time practices were catered by the farmer. The alfalfa farm life time was estimated to be 6 years, categorized as follow: 1 year of low yield due to establishment of the farm and young plants, 4 years of full production, and 1 years of low yield due to aging plants, and then the destruction of the farms.

The input from environmental sources of energy (radiation, wind, rain, soil organic matter and soil) was not considered in the survey (Tzivilakis et al., 2005). Agricultural inputs comprise electricity, human labor, diesel fuel, chemical fertilizers, pesticides (biocides), machinery and seed. In order to assess the output energy, values of dry hay (15% w.b.) was measured. Flow (all energy input utilized during 2014) and stock (accounting energy inputs utilized for the whole farm lifetime duration) resources were listed in Table 1. Total flow and stock energy inputs and output converted into the energy equivalents by multiplying the quantities of the input and output with appropriate energy coefficients.

Energy indices (energy use efficiency, energy productivity, specific energy and net energy) were computed for alfalfa

Table 1

Energy equivalents of input and output in alfalfa production systems.

Inputs and output	Unit	Energy equivalents (MJ unit ⁻¹)	Reference
Stock resource			
Machinery (tillage/disc/planting/fertilizer spreader)	h	62.70	Samavatean et al. (2010)
Diesel fuel	l	51.33	Samavatean et al. (2010)
Seed	kg	28.1	Samavatean et al. (2010)
Farmyard manure	kg	0.3	Soltani et al. (2013)
Human labor	h	1.96	Yousefi and Mohammadi (2011)
Flow resource			
Machinery (fertilizer spreader/ harvest/transport)	h	62.70	Samavatean et al. (2010)
Diesel fuel	l	51.33	Samavatean et al. (2010)
N fertilizer	kg N	60.6	Ozkan et al. (2004)
P fertilizer	kg P2O5	11.1	Ozkan et al. (2004)
K fertilizer	kg K2O	6.7	Ozkan et al. (2004)
Human labor	h	1.96	Yousefi and Mohammadi (2011)
Pesticides	kg	120.	Mandal et al. (2002)
Electricity	kWh	3.6	Gundogmus (2006)
Output	kg		
Dry hay (15% w.b.)	kg	14.7	Ghasemi Mobtaker et al. (2012)

Table 2

Emissions of GHGs (g) per unit of different input and their global warming potential (GWP) in alfalfa production systems.

Inputs	CO ₂	N ₂ O	CH ₄	Reference
Diesel fuel (l)	3560.00	0.70	5.20	Kramer et al. (1999)
Electricity (kWh)	61.20	8.82	0.02	Tzilivakis et al. (2005)
Nitrogen fertilizer (kg)	3100.00	0.03	3.70	Snyder et al. (2009)
Phosphorous fertilizer (kg)	1000.00	0.02	1.80	Snyder et al. (2009)
Potassium fertilizer (kg)	700.00	0.01	1.00	Snyder et al. (2009)
Pesticides	5100	0.02	0.01	Green (1987)
GWP CO ₂ e factor	1	310	21	Tzilivakis et al. (2005)

production systems using the following equations (Asgharipour et al., 2012; Soltani et al., 2013):

$$\text{Energy use efficiency} = \frac{\text{Energy output (MJ ha}^{-1}\text{)}}{\text{Energy input (MJ ha}^{-1}\text{)}} \quad (2)$$

$$\text{Energy productivity} = \frac{\text{Crop output (kg ha}^{-1}\text{)}}{\text{Energy input (MJ ha}^{-1}\text{)}} \quad (3)$$

$$\text{Specific energy} = \frac{\text{Energy output (MJ ha}^{-1}\text{)}}{\text{Crop output (kg ha}^{-1}\text{)}} \quad (4)$$

$$\text{Net energy} = \text{Energy output (MJ ha}^{-1}\text{)} - \text{Energy input (MJ ha}^{-1}\text{)}. \quad (5)$$

All inputs consumed in alfalfa production is classified into direct (DE) and indirect (IDE), renewable (RE) and nonrenewable (NRE) sources and commercial energy (CE) and non-commercial energy (NCE) (Singh et al., 2007). The sources of DE consists human labor, diesel fuel, and electricity while indirect energy sources are incorporated of machinery, seed, pesticides and chemical fertilizers. RE encompass human labor and seed and NRE includes of electricity, machinery, diesel fuel, pesticides, and chemical fertilizers. CE consists electricity, diesel fuel, pesticides, chemical fertilizers, seeds, machinery and NCE includes human labor. The input related to each group (DE, IDE, RE, NRE, CE and NCE) were calculated and finally different groups of energy were assessed.

2.3. Estimate of greenhouse gases (GHGs) emissions and global warming potentials (GWPs)

In this study the amounts of GHGs emissions associated with input production and use of farm machinery were quantified and expressed in terms of CO₂-equivalent (CO₂e). GHGs assessed included CO₂, CH₄ and N₂O. Table 2 summarizes the GHGs emissions dependent with the different inputs in alfalfa production per hectare. GHGs emissions can be estimated and expressed

per unit of the land used in crop production, per unit weight of product, and per unit of energy input or output (Soltani et al., 2013). The amount of produced CO₂ was computed by multiplying the quantities of consumed input (diesel fuel, chemical fertilizers, machinery and pesticides) by using specific emission coefficient of agricultural inputs. The global warming potential of CH₄ and N₂O over a 100 year time horizon has been estimated to be approximately 21 and 310, respectively (IPCC, 2007).

In the last part of the study the total emissions of greenhouse gases are determined as follows (Kramer et al., 1999):

$$\text{Greenhouse effect} = \sum \text{GWP}_i \times m_i$$

where m_i is the mass (in kg) of the emitted gas. The score is expressed in terms of CO₂e.

3. Results

3.1. Energy use pattern in alfalfa production systems

The energy equivalents for total inputs used and output for alfalfa production in whole production life along with share of energy input categories in the total input energy are indicated in Table 3. The results indicated that approximately 156 h of machinery and 885 h of human labor per hectare were needed to produce alfalfa in the surveyed region. The total energy used in the farm operations for alfalfa production and gross energy output were 313.52 GJ ha⁻¹ and 962.85 GJ ha⁻¹ for establishment and 6 years production life, respectively. Among all input energy electricity ranked first (72.5% of total energy input). Apart from electricity, the energy input due to diesel fuel consumption (12.3%), chemical fertilizers (8.6%) and machinery (3.1%) were the second, third and fourth most important input factors. The most portion of electricity energy was utilized in irrigation systems to pumping water from wells. Other input energy had shares of less than 5%.

Table 4 lists results of energy indicators (energy use efficiency, energy productivity, specific energy and net energy) for alfalfa

Table 3
Energy inputs, outputs and the ratio in alfalfa production systems.

Inputs and output	Quantity per unit area (ha)	Total energy equivalents (MJ ha ⁻¹)	Percentage of total energy input (%)
Input (Stock + flow resources)			
Machinery (h)	155.65	9759.255	3.1
Human labor (h)	884.57	1733.7572	0.6
Diesel fuel (l)	751.00	38 548.83	12.3
N fertilizer (kg)	313.50	18 998.1	6.0
P fertilizer (kg)	729.42	8096.562	2.6
K fertilizer (kg)	5.11	34.237	0.1<
Farmyard manure (kg)	24 450	7335	2.3
Pesticides (kg)	4.12	494.4	0.2
Electricity (kWh)	63 125	227 250	72.5
Seed (kg)	45.14	1268.434	0.4
Output			
Dry hay (15% w.b.)	65 500	962 850	–

Table 4
Energy indicators and different form of energy in alfalfa production systems.

Item	Unit	Quantity	Percentage (%)
Energy input	MJ ha ⁻¹	313 518.6	–
Energy output	MJ ha ⁻¹	962 850.0	–
Energy use efficiency	–	3.07	–
Energy productivity	kg MJ ⁻¹	0.209	–
Specific energy	MJ kg ⁻¹	4.79	–
Net energy	MJ ha ⁻¹	36 167.45	–
Direct energy ^a	MJ ha ⁻¹	267 532/6	85
Indirect energy ^b	MJ ha ⁻¹	45 986/0	15
Renewable energy ^c	MJ ha ⁻¹	303 181/4	3
Non-renewable energy ^d	MJ ha ⁻¹	10 337/2	97
Non-commercial energy ^e	MJ ha ⁻¹	1733/8	1
Commercial energy ^f	MJ ha ⁻¹	311 784/8	99

^a Includes diesel fuel, human labor and electricity.

^b Includes machinery, seed, pesticides, farmyard manure and chemical fertilizer.

^c Includes human labor, farmyard manure and seed.

^d Includes diesel fuel, machinery, electricity, pesticides and chemical fertilizer.

^e Includes human labor.

^f Includes diesel fuel, machinery, pesticides, electricity, chemical fertilizer, farmyard manure and seed.

production. Energy use efficiency value of alfalfa production was determined as 3.07. The result of energy ratio was higher than the values of 1.82–2.06 (Ghasemi Mobtaker et al., 2011) for alfalfa production. Energy productivity was calculated as 0.209 kg MJ⁻¹. This is meaning that produced alfalfa dry hay per unit input energy was 0.209 kg. This amount reported 0.27 for alfalfa production (Ghazvineh and Yousefi, 2013). Specific energy and net energy for alfalfa production systems was calculated as 4.79 MJ kg⁻¹ and 36 167.45 MJ ha⁻¹, respectively. This amounts was reported at 8.48 MJ kg⁻¹ and 708 411 MJ ha⁻¹ for alfalfa in Iran (Ghasemi Mobtaker et al., 2011).

Table 4 presents the distribution of energy input in alfalfa production from direct (DE) and indirect (IDE), renewable (RE) and non-renewable (NRE) and commercial (CE) and non-commercial (NCE) forms. Results revealed that DE consumption was higher than IDE in alfalfa farms; the same was obtained for NRE vs. RE and NCE vs. CE energy sources. This demonstrates that alfalfa production depends mostly on non-renewable energy (electricity, diesel fuel and chemical fertilizers) in the surveyed area.

3.2. GHGs emissions and GWP in alfalfa production systems

Estimates of GHGs emissions for different items in farms is summarized in Table 5. Emissions amount of CO₂, N₂O and CH₄ from alfalfa production systems were 8262.67 kg ha⁻¹, 557.31 kg ha⁻¹ and 7.65 kg ha⁻¹, respectively. The value of total GWP was estimated at 181 190 kg CO₂e ha⁻¹ for alfalfa production systems. Electricity with a share of 97.4% had the highest emission, followed by diesel fuel (1.6%), N fertilizers (0.6%), and P fertilizer

(0.4%). Emission of CO₂ consisted more than 93% of GHGs emissions and the share of other two gases, i.e., N₂O and CH₄ was less than 7%. In terms of CO₂e, however, 95.3 of the GWP originate from N₂O, 4.6% from CO₂, and 0.1% from CH₄. GHGs emissions from alfalfa production in this study are lower than those reported (19 137 kg CO₂e ha⁻¹) by Ghazvineh and Yousefi (2013) for alfalfa production under condition of Iran. Also, the results showed that alfalfa production in the studied systems would lead to 2.77 kg CO₂e kg⁻¹ of produced hay and 0.19 kg CO₂e MJ⁻¹ of output energy. The amount of CO₂e per kg for alfalfa hay production was reported as 0.998 (Khoshnevisan et al., 2013a).

4. Discussion

4.1. Energy use pattern in alfalfa production systems

The energy input for alfalfa production in the Sistan region was found to be 313.52 GJ ha⁻¹ (Table 4). Our results of energy input is closer to the results (496.9 GJ ha⁻¹) reported by Ghazvineh and Yousefi (2013) for 6 years from alfalfa agro-ecosystems in Kermanshah province of Iran. However, estimates of energy input from this study are lower than 810.57 GJ ha⁻¹ for whole production life (7 years) of alfalfa hay production during 2001–2007 growing seasons (Ghasemi Mobtaker et al., 2012) and 72.33–82.16 GJ ha⁻¹ for total energy used in 7 years production life of alfalfa in different irrigation systems (Ghasemi Mobtaker et al., 2011) in the Hamedan province of Iran. Also, Zahmatkesh et al. (2013) in their research reported that the total energy input in alfalfa production was 62.7 GJ ha⁻¹ while the output energy was 240.0 GJ ha⁻¹ for whole production life and establishment in Zanjan province of Iran. Average yield of alfalfa (for 6 years) was found to be 65 500 kg ha⁻¹ and the total energy equivalents was 962.85 GJ ha⁻¹ (Table 4). This amount compares to 1525.21 and 1530.02–1491.52 GJ ha⁻¹ in 7 years as reported by Ghasemi Mobtaker et al. (2012, 2011), respectively.

The results indicated that the consumption of electricity, diesel fuel and chemical fertilizers was high for alfalfa production in the region (Table 3). Excessive use of electricity, fuel and chemical fertilizers in the farm may create serious environmental consequences (Khan et al., 2009). These findings were in agreements with Ghasemi Mobtaker et al. (2011, 2012) and Tsatsarelis and Koundouras (1994) where electricity consumption, fuel and chemical fertilizers were major energy inputs for alfalfa production. The electricity utilization in alfalfa production is for irrigation. The reasons of high electrical energy consumption is not using modern and efficient irrigation methods and having deep wells in the surveyed region. With the purpose of reducing electricity consumption, employing of modern irrigation methods can be suggested which leads into saving water consumption for irrigation. The energy contribution of N fertilizer was nearly 70% of total energy of

Table 5Gaseous emissions (kg ha^{-1}) from different input and their GWP in alfalfa production systems.

Inputs	CO ₂	N ₂ O	CH ₄	GWP	Percentage of different inputs in GWP (%)
Diesel fuel	2673.56	0.53	3.91	2918.536	1.6
Electricity	3863.25	556.76	1.26	176 486.1	97.4
Nitrogen fertilizer	971.85	0.009	1.16	999.1245	0.6
Phosphorous fertilizer	729.42	0.015	1.31	761.5145	0.4
Potassium fertilizer	3.58	5.11E–05	0.005	3.700151	0.1<
Pesticides	21.01	8.24E–05	4.12E–05	21.03841	0.1<
Total emission	8262.67	557.31	7.65	–	–
GWP CO ₂ equivalence	8262.67	172 766.80	160.56	–	–

utilized chemical fertilizers. As alfalfa is a N-fixing plant, the nitrogen fertilizer can be replaced by other fertilizers like phosphorus, potassium, and even farmyard manures. The most remarkable causes for the high chemical fertilizers use are lack of nutrients in soil, high organic fertilizer price and low chemical fertilizers price and farmer's poor knowledge (Pishgar-Komleh et al., 2011). A good agronomic management strategy can minimize nitrogen fertilizer consumption via using the appropriate source, at the right time, at the right rate and with the right placement (Snyder et al., 2009). In addition, employing efficient machineries and tractors with high energy use efficiency in the operations is favorable to reduce the amount of diesel fuel energy in the total input energy.

Pesticides energy had the lowest share of the total energy input with 494.4 MJ ha^{-1} . The similar findings have been expressed in the literature which shows that energy input of pesticides has a little share of total energy input in crops production (Asgharipour et al., 2012; Soltani et al., 2013).

The value of energy use efficiency obtained in this study (3.07) indicates the efficient consumption of energy in alfalfa production in the research area, but it was lower than 4.83 reported by Ghazvineh and Yousefi (2013). This value was 3.51 for rain-fed barley production systems in Iran (Yousefi and Ghazvineh, 2011), 2.14 for corn in Turkey (Pimentel and Burgess, 1980), 1.58 for kiwifruit in Iran (Mohammadi et al., 2010), 4.83 for alfalfa in Iran (Yousefi and Mohammadi, 2011), 2.8 for greenhouse vegetable in Turkey (Ozkan et al., 2004), 2.99 and 5.10 for greenhouse and open-field grape in Turkey (Ozkan et al., 2007), 0.017 and 0.33 for greenhouse and open-field cucumber in Iran (Yousefi et al., 2012). By using less energy in electricity, diesel fuel and nitrogen fertilizer, more energy ratio would be achieved. In this study, the energy productivity of 0.209 kg MJ^{-1} was observed (Table 4). For forage and root crops whose economic yield is equals to biologic yield, this indicator is high, but energy productivity seems to be lower in cereal and other grain crops because of lower denominator.

The share of DE, IDE, RE and NRE inputs were calculated as 85, 15, 3 and 97%, respectively (Table 4). Therefore, it is clear that non-renewable energy consumption was higher than that of renewable in alfalfa production, which is in agreement with the literatures for different crops (Khoshnevisan et al., 2013a,b; Ozkan et al., 2007, 2004; Soltani et al., 2013). Since the main non-renewable inputs were electricity and chemical fertilizers, efficient use of water and management of plant nutrients using renewable resources like farmyard manure would increase the rate of renewable energy.

The electricity energy had the highest share in DE while the share of diesel fuel and chemical fertilizers energy in IDE was the highest. The high rate of DE inputs, NRE and CE reflects an intensive use of electricity, diesel fuel and chemical fertilizers in the surveyed area. Significant dependency of these production systems on electricity, fossil fuels and chemical fertilizers decreases the energy use efficiency (Pimentel and Burgess, 1980) and increases the emissions of greenhouse gases. Since the main NRE inputs were electricity, efficient use of water would increase the rate of RE. Similar findings were reported by other researchers that the ratio of DE is higher than IDE, and the rate of NRE and CE is greater than RE and NCE consumption in different cropping systems (Ozkan

et al., 2004; Asgharipour et al., 2012; Khoshnevisan et al., 2013b; Soltani et al., 2013). Ghasemi Mobtaker et al. (2012) found that the share of DE, IDE, RE and NRE in alfalfa production systems of Hamedan province were 84%, 16%, 1% and 99%, respectively.

4.2. GHGs emissions and GWP in alfalfa production systems

Improving the sustainability of agricultural production systems needs the admission of farming practices that not only, affordable supply high-quality food in sufficient quantity but also assure minimizing negative environmental impacts (Liebig et al., 2007). Iran is the world's eighth largest emitter of GHGs, and a large proportion of GHGs in Iran emits from agricultural sector (Fallahi and Hekmati Farid, 2013). A great reduction of GHGs can be achieved if there are restrictive overuse of non-renewable external inputs policies. In the present study, GHGs emissions for alfalfa production was $181\,190 \text{ kg CO}_2\text{e ha}^{-1}$ corresponding to $2.77 \text{ kg CO}_2\text{e kg}^{-1}$ of produced hay (Table 5). To our knowledge, this is the first work that estimates of GHGs emissions for alfalfa production systems in Iran. In other studies conducted in Iran Soltani et al. (2013) reported 173 and $474 \text{ kg CO}_2\text{e t}^{-1}$ for wheat production in Khoshnevisan et al. (2014) calculated total GHG emission as $116.4 \text{ kg CO}_2\text{e t}^{-1}$ of potato produced in Fereydonshehr.

The emissions were mainly due to electricity production, which accounted for 97.4% of the total GWP. In the other studies in Iran the highest quantity of GHGs emissions was belonged to electricity and irrigation (Khoshnevisan et al., 2013a,b). The generation processes of electricity emit a great quantity of N₂O, as well as CO₂. Applying more efficient electric water pumps and using of renewable energy sources to generate electricity (like solar energy and wind sources) would lead to less GHG emissions. In addition, having integrated farms due to less energy utilization and high yield would helping us to get the benefit of more environmentally friendly and sustainable alfalfa production.

5. Conclusion and recommendations

Energy use and GHGs emissions from agro-ecosystems is considered to be a key indicator of sustainable development. This study examined the energy consumption, emissions of GHGs and GWP of alfalfa production in Sistan. Alfalfa cultivation is one the most important agricultural activity throughout the region. Data were collected from 110 alfalfa farmers through questionnaire survey. The results indicated that the total averages input and output energy of alfalfa production systems in whole production life (6 years) were $313\,518.6$ and $962\,850.0 \text{ MJ ha}^{-1}$, respectively. The highest contribution of input energy was recorded for electricity (72.5%), Diesel fuel (12.3%), N fertilizer (6.0%) and machinery (3.1%), respectively. Energy use efficiency, energy productivity and net energy were 3.07 , 0.209 kg MJ^{-1} , 36.17 GJ ha^{-1} , respectively. The share (relative distribution-portion) of DE, IDE, RE, NRE, CE and NCE forms in alfalfa production were 85%, 15%, 3%, 97%, 1% and 99%, respectively. Employing new electrical pumps to water pumping and decreasing consumption

of diesel fuel should be taken into consideration to decrease the amount of NRE use in the studied region. This will lead to less water and soil pollution and makes the alfalfa production environment friendly.

The GWP analysis revealed that the amounts of CO₂, N₂O and CH₄ emissions were 8262.67 kg ha⁻¹, 557.31 kg ha⁻¹ and 7.65 kg ha⁻¹, respectively. It was concluded that the total GWP in alfalfa agro-ecosystems was 181 190 kg CO₂e ha⁻¹, 2.77 kg CO₂e per kg of produced dry hay and 0.19 kg CO₂e MJ⁻¹ of output energy. In terms of CO₂e, 95.3 of the GWP originate from N₂O, 4.6% from CO₂, and 0.1% from CH₄. Electricity with a share of 97.4% played the most important role on the total GHGs emissions and it was followed by diesel fuel (1.6%), N fertilizer (0.6%) and P fertilizer (0.4%). Altering the common irrigation systems to modern ones and introducing and implementing reduced (conservation) tillage would greatly reduce energy use and GHGs emissions from alfalfa production in the region. As a result, we need to expand sustainable alternative energies to fossil fuels in order to reduce energy demand, Environmental crises, thereby stabilizing GHGs emissions and minimizing expected global warming.

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