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Research paper

Assessment of the amount of inputted energy and discharged greenhouse gasses from wheat cultivation in Ardabil province of Iran

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A R T I C l E I N F O

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A B S T R A C T

preventing greenhouse gasses discharge and proper environment maintenance is crucial for human race. For a sustained agricultural development, managing energy consumption and greenhouse gasses discharge (GHG) is important in all agricultural agroecosystem. This study aims to compare wheat cultivation in irrigated and dryland wheat production using energy usage-based greenhouse gas discharge in diverse climatic areas. Throughout 2019, a face-to-face questionary was used to obtain data from wheat cultivators. The total energy usage according to gathered data are 14975 and 54963.9 MJ ha−1 for dryland and irrigated wheat production. In dryland wheat production, energy consumption efficiency was 16% higher compared to energy consumption efficiency of irrigated wheat production. The total amount of GHG for dryland wheat production was 370.5 kg CO2-eq t−1 and 520.62 kg CO2-eq ha−1 and for irrigated wheat production, total GHG was 620.8 kg CO2-eq t−1 and 2986.71 kg CO2-eq ha−1. The order of GHG from low to high in dryland wheat production was chemical fertilizers, machinery, and diesel fuels. In order to reduce the GHG and its environmental effect, efficient energy consumption is vital in wheat production.

Introduction

Durum wheat is one of the most important crops reaching a share of 36 million tons of annual worldwide crop product (Triticum durum Desf.) (Gholamin and Khayatnezhad 2012). World's leading durum wheat producers are Canada and turkey each reaching 2 million ha's, after them with 1.5 million ha's are India, Italy, and Algeria (Khayatnezhad 2012), (Khayatnezhad and Gholamin 2012; Tidiane Sall et al. 2019). Scientist came to agreement that the main polluters for global warming are nitrous oxide (N_2O), methane (CH_4), and carbon dioxide (CO_2) which are major threats for environment in future (Pathak and Wassmann 2007). A major GHG sources are agricultural production and their activities. Agriculture sector can allocate up to 10 to 12 percent of GHG for itself with emissions reaching 5.1–6.1 Pg CO2e year−1 (Asgharipour, Mousavinik, and Enayat 2016b). the largest proportions of these discharges come from carbon changes of soil and energy consumption for CO_2, arable lands for N_2O, and animal productions for NH_4 (Asgharipour, Mousavinik, and Enayat 2016b). additionally, the GHG will increase with food demand rising in the future (Gilbert 2011). One challenge that agriculture sector faces is minimization of carbon footprint specifically GHG in agricultural products (Williams and Wikström 2011). The high amount of GHG particularly CO_2 discharged from human related activities and its effect on climate changes turned into big political and ecological problem in the past decades, such as increase of CO_2 density to 380 ppm from 280 ppm through 1700 to 2006 (IPCC, 2007). There is a possibility for massive climate alterations in near future in case of the continuation of the current increasing trend of GHG (Mondani et al. 2017). due to impossibility of exact prediction of climate changes, the details of pollution forecast in future are arguable, but most scientists believe that temperature increase in future will have negative effects on agricultural and natural ecosystems and human development (Fischlin et al. 2007). It is believed that reducing GHG can prevent global warming (Meinshausen et al. 2009). Thus realization of GHG that is discharged from different agricultural actions and systems is important for reducing harmful emissions in different areas.

Use of fossil fuels has a large contribution to air pollution and climate changes, additionally; it is a limited resource which should be saved for upcoming generations. Energy usage is closely related to agricultural systems. Agricultural production is both an energy consumer and generator (Alam, Alam, and Islam 2005). Due to human population increase in past years, energy consumption has consequently increased in agriculture in response to desire of humans to increase living standards and limitations of arable land (Banaeian, Omid, and Ahmadi 2011). In reality, agriculture's share of total CO_2 emissions is only 13%. However, it contributes to 60% of total N_2O discharge and 50% of total CH_4 emissions (Mondani et al. 2017).

Recently, Iran's agriculture energy usage has became matter of discussion due to the increasing energy costs, energy demand, and more mechanization in agricultural practices (Mohammadi et al. 2014). In recent years, there has been an increasing number of studies involving agricultural products such as chickpea (Koocheki et al. 2011), lintel, been, tomato (Moghaddam, Feizi, and Mondani 2011), grain corn and cotton (Zahedi, Mondani, and Eshghizadeh 2015), and wheat (Ghorbani et al. 2011), but unfortunately, few studies actually considered reviewing GHG in those sections (Yousefi, Khoramivafa, and Mondani 2014).

Iran's agricultural productions take place in diverse climatic areas and different soil conditions, therefore, quantifying energy usage and GHG for each climate is important.

Perennial and annual crops should be differentiated in evaluation of environmental pressure in crop production (i Canals, Burnip, and Cowell 2006). One important difference is GHG and energy usage in perennial and annual crops in which, one requires annual resource use and one has resources that exist throughout the farm's entire lifespan. Thus, this study focused on determining the total inputted energy of fossil fuels, machinery, chemical fertilizers, pesticides, labor and electricity together with production and region related GHG throughout the entire production lifetime of Ardabil province of Iran.

Methods and materials

Studying regions

Ardabil province of Iran is the main area which this study took place. It is situated in 48 degrees and 30 minutes of eastern longitude with 38 degrees and 15 minutes of north latitude standing 1350 meters high from sea level. As measured in 2019, the total area for wheat farming in Ardabil province was approximately 37500 ha, with 19000 ha of irrigated and 18500 ha of dryland wheat farms. Different growing circumstances govern the wheat cultivation. Thus, five climatic areas were organized for Ardabil province based on data gathered from central meteorological center (Fig 1).

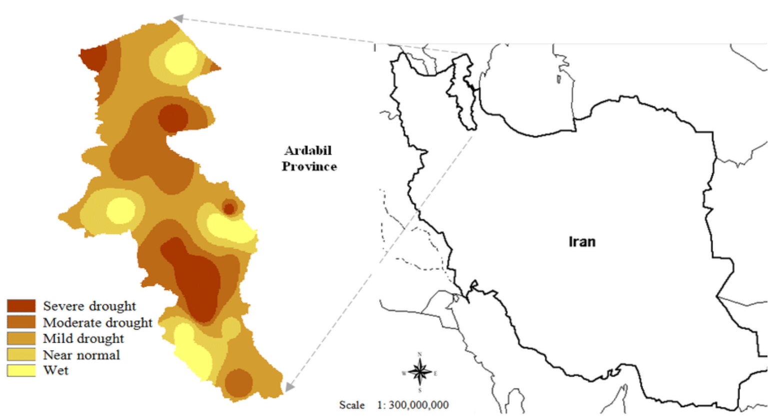

Fig 1. SPI based study area drought zoning map (Sookhtanlou 2018)

Analysis of energy

For quantification of dryland and irrigated wheat production relationship and their GHG and energy usage, a face-to-face questionary was used for gathering data from growers in different climatic areas throughout year 2019. Neyman method was utilized to calculate the study sample size (EQ 1), (Yamane 1967).

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

In this equation *N* represents the quantity of total population, *n* shows the sample size, *Sh* represents the *h* stratification's standard deviation and *Nh* shows the number of population in stratification *h*, D^2 is d^2/z^2 where *d* stands for the allowed error ratio which is deviated from mean population of $(\overline{X} - \bar{x})$, and finally *z* represents the coefficient of reliability (95% confidence which is represented by 1.96). the error that can be allowed in the studied population can not exceed 5% and it should be within 95% confidence.

The data that were gathered from farmers using questionary was generalized and averaged to 1 ha. For approximation of inputted energy, the amounts of wheat cultivation farms, machinery, seeds, chemical fertilizers (micro fertilizers, potassium, phosphate, and nitrogen), farmyard manure, diesel fuel, human labor, and herbicides and pesticides (kg or liters). Were multiplied by their equivalent energy figures (table 1).

The outputted form of energy in wheat farms were straw and grain. Harvesting machines were usually the means to collect the grain yield, and the packing machines were used to collect the straw, and their residues were then returned back into soil. For estimation of outputted energy, the straw and grain yields and their corresponding energy were multiplied (table 1). The amount of output and input energy in this study were shown in MJ which equals to 106 J. the measurement of the energy indices such as net energy, specific energy, energy productivity, and energy consumption efficiency were carried out using the equations seen below (Asgharipour, Mousavinik, and Enayat 2016b; Mondani et al. 2017):

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

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

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

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

Table 1. Output and input energy equivalent in wheat production systems

Inputs and output	Unit	Energy equivalent (MJ)	References
A. Input			
1. Human Labor	h	1.95	(Taylor, O'Callaghan, and Probert 1993)
2. Machinery	h	62.7	(Samavatean et al. 2011)
3. Diesel fuel	L	50.23	(Samavatean et al. 2011)
4. Fertilizers			
- Nitrogen	kg	75.46	(Taylor, O'Callaghan, and Probert 1993)
- Phosphate	kg	13.07	(Taylor, O'Callaghan, and Probert 1993)
- Potassium	kg	15.11	(Demircan et al. 2006)
- Micro	kg	120	(Taylor, O'Callaghan, and Probert 1993)
5. FYM	kg	0.3	(Yilmaz, Akcaoz, and Ozkan 2005)
6. Biocides			
- Herbicide	L	295	(Mohammadi et al. 2014)
- Insecticide	L	199	(Taylor, O'Callaghan, and Probert 1993)
- Fungicide	kg	181.9	(Taylor, O'Callaghan, and Probert 1993)
7. Electricity	kWh	3.6	(Taylor, O'Callaghan, and Probert 1993)
8. Water	m^3	0.63	(Ozkan, Akcaoz, and Fert 2004)
9. Seeds	kg	20.1	(Samavatean et al. 2011)
B. Outputs			
1. Grain Yield	kg	14.7	(Mobtaker, Akram, and Keyhani 2012)
2. Straw Yield	kg	12.5	(Ozkan, Akcaoz, and Fert 2004)

Greenhouse Gasses Discharge (GHG)

Emissions are reported as equivalents of CO2 (CO2-eq) considering the GWP of different forms of GHG units (Jones et al., 2012). The coefficient of CO2 discharge was used as GHG amount estimation from the inputs in dryland and irrigated wheat production (table 2). Also, the implementation of diesel fuel (L), chemical fertilizers (kg), electricity (kWh), machinery (MJ), farmyard manure (kg), and biocides (kg) was done via multiplying their amounts with the equivalent discharge coefficient. Additionally, GHG per output and input energy (kg CO2 per corresponding MJ), per unit weight (kg CO2 per corresponding ton of wheat), and per area unit (kg CO2 per corresponding hectares) were measured separately.

Table 2. the GHG coefficient (kg CO_2-eq unit^{-1})

Inputs	Unit	GHG coefficient	References
1. Machinery	MJ	0.071	(Pishgar-Komleh, Omid, and Heidari 2013)
2. Diesel fuel	L	2.76	(Khoshnevisan et al. 2013)
3. Fertilizers			
- Nitrogen	kg	1.3	(Lal 2004)
- Phosphate	kg	0.2	(Lal 2004)
- Potassium	kg	0.15	(Lal 2004)
4. FYM	kg	0.126	(Mondani et al. 2017)
5. Biocides			
- Herbicide	kg	6.3	(Lal 2004)
- Insecticide	kg	5.1	(Lal 2004)
- Fungicide	kg	39	(Lal 2004)
6. Electricity	kWh	0.78	(Mondani et al. 2017)

Results and discussion

Inputted energy in dryland and irrigated wheat production

The outcome of the test showed that regardless of climate differences in different areas, the mean energy used throughout crop production in dryland and wheat production, were 18351.8 MJ and 54963.9 MJ ha^{-1}, consequently. In an irrigated wheat production system, the most energy consuming practice through the whole process is diesel fuels allocating (50.23%) of total energy usage to itself, following the diesel fuel are chemical fertilizers, electricity, seed, and water used in irrigation with (16.31%), (10.84%), (8.52%), and (6.65%), respectively (Fig 2). In case of dryland wheat production, the most energy consuming practice was diesel fuels (48.03%) followed by seed, chemical fertilizers, and machinery with (24.04%), (16.74%), and (8.76%) respectively (Fig 2). The reason for more energy usage in irrigated wheat production in comparison to dryland wheat production was the higher energy consumption in diesel fuels, electricity that was used for pumping water, and more agricultural machinery usage. Additionally, other reasons were more nutrients consumption and seed usage due to higher density of plants in a farm (table 3). Moreover, human labor was noticeably more in irrigated wheat production compared to dryland wheat production (table 3). This might be due to more agricultural practices throughout the irrigated wheat cultivation process compared to that of dryland production. Studies in Khorasan province in Iran also indicated that total inputted energy in dryland and irrigated wheat production was 9354 MJ and 45367 MJ ha^{-1} consequently (Ghorbani et al. 2011). It was found that in Khorasan, inputted energy for electricity, chemical fertilizers, and diesel fuels in irrigated wheat production system was 4320.0, 16 843.1, and 10950.2 MJ ha^{-1} consequently. Other studies conducted on different products also yielded similar outcomes, some of them are studies conducted on chickpea in irrigated and dryland production (Koocheki et al. 2011), and sugar beet (Asgharipour, Mondani, and Riahinia 2012). Also, Mondani et al. 2017 conducted a study in Kermanshah province on wheat production in dryland and irrigated wheat production systems which showed that the total inputted energy for dryland and irrigated wheat production was 15614.9, and 53082.9 MJ ha^{-1}, respectively.

Table 3: output and input energy in wheat production (MJ ha^{-1})

Inputs and output	Irrigated	Dryland
A. Input		
1. Human Labor	118.9	32.8
2. Machinery	2109.7	1312.1
3. Diesel fuel	27608.7	7192.8
4. Fertilizers		
- Nitrogen	7765.5	2215.7
- Phosphate	591.5	292.7
- Potassium	348.2	-
- Micro	264.8	-
5. FYM	781.8	-
6. Biocides		
- Herbicide	557.9	117.0
- Insecticide	181.8	124.8
- Fungicide	328.7	88.9
7. Electricity	5961.9	-
8. Water	3657.1	-
9. Seeds	4687.4	3598.2
Total inputs	54963.9	14975
B. Outputs		
1. Grain Yield	73100.0	21457.8
2. Straw Yield	79400.0	26876.1
Total outputs	152500	48333.9

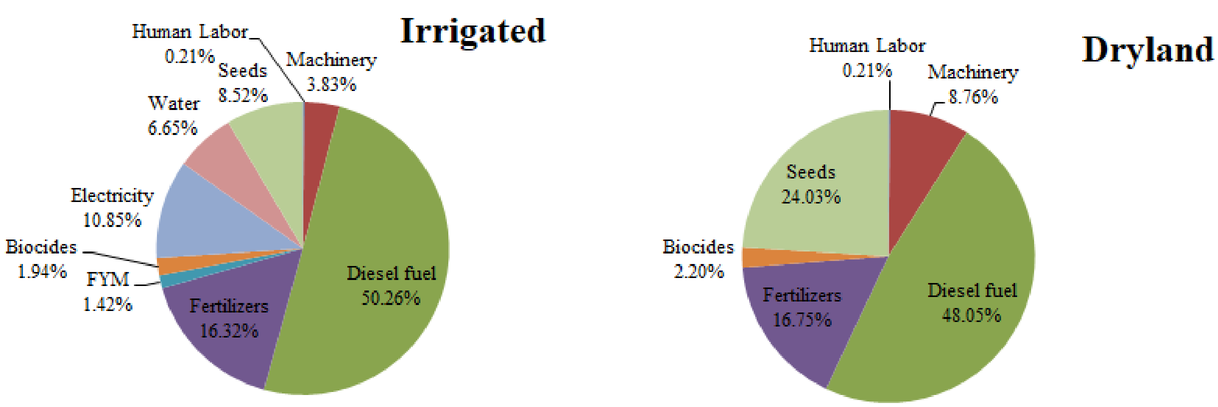

Figure 2: most noticeable energy consumers in dryland and irrigated wheat production.

Outputted form of energy in dryland and irrigated wheat production system

The total outputted energy in form of straw and grain yield in dryland and irrigated wheat production system, regardless of results, were measured at 48333.9 and 152500 MJ ha^{-1}, consequently (table 3). The irrigated wheat production had about 68.3% more outputted energy which was due to higher inputted energy compared to dryland wheat production, similar to what Mondani et al. (2017), reported in his studies. Additionally, obtained results showed that lowest and highest outputted energy in irrigated wheat production was measured at 21457.8 MJ ha^{-1} in dryland wheat production and 79400 MJ ha^{-1} in form of straw output consequently (table 3).

Energy indicators in dryland and irrigated wheat production

The mean energy consumption efficiency, regardless of results, was measured to be 3.22 and 2.77 which indicates that the produced energy was 3.22 and 2.77 times each unit of consumed energy in dryland and irrigated wheat production, consequently (table 4). The energy ratio is utilized in energy balances as an indicator to assess the energy consumption efficiency in wheat cultivation (Kuesters and Lammel 1999). In dryland wheat production the mean energy consumption efficiency was almost 16.24% more compared to irrigated wheat production which means that dryland produces more goods per energy used compared to irrigated wheat production. The lower energy consumption efficiency in irrigated wheat production might come from higher overall energy usage. Other studies conducted on energy ratio showed that in irrigated wheat production, energy use was 1.4 and in dryland it was 3.4 (Ghorbani et al. 2011), for dryland chickpea production it was 2.9, and 1.2 for irrigated wheat production (Koocheki et al. 2011), and finally, it was 13.4 for sugar beet production (Asgharipour, Mondani, and Riahinia 2012). Hence, it means that selecting reasonable wheat production environment is vital for sustained energy usage.

The obtained outcome of this paper suggests that mean produced energy in dryland and irrigated wheat production were measured at 0.086 and 0.081 (table 4). This indicates that 0.086 and 0.081 number of outputs were gained from one energy unit consumed in dryland and wheat production, consequently (table 4). Energy production plays an important role as an energy index in assessing wheat production systems in the matter of energy output and energy usage. With higher energy production potential in wheat production lower energy usage and more sustained production and thus more secure production system can be achieved. Other studies also considered energy production potential of different systems and different crops (Ghorbani et al. 2011; Koocheki et al. 2011; Mondani et al. 2017).

Table 4: overall inputted energy measured in form of non-renewable and renewable, indirect and direct energy indices for dryland and irrigated wheat production.

	Irrigated	Dryland
Energy use efficiency	2.77	3.22
Specific energy (MJ kg^{-1})	12.21	11.51
Energy productivity (kg MJ^{-1})	0.081	0.086
Net energy (MJ ha^{-1})	97536.1	44735.7
[a] Direct energy (MJ ha^{-1})	37346.6	7225.6
[b] Indirect energy (MJ ha^{-1})	17617.3	7749.4
[c] Renewable energy (MJ ha^{-1})	9245.2	3631
[d] Non-renewable energy (MJ ha^{-1})	45718.7	11344
Total energy inputs (MJ ha^{-1})	207479	74700.53

a Includes Human labour, Diesel fuel, Electricity, Irrigation water.
b Machinery, Chemical fertilizers, Chemical pesticides, FYM, Seed.
c Human labour, FYM, Seed, Irrigation water.
d Machinery, Diesel fuel, Electricity, Chemical fertilizers, Chemical pesticides.

Table 4 also shows the non-renewable and renewable, indirect and direct inputted forms of energy. Direct energy was measured at 7225.6 MJ ha^{-1} for dryland wheat production and 37346.6 MJ ha^{-1} in irrigated wheat production. This might be regarding the dryland wheat production's capability of not using electricity, irrigation related water, and farmyard manure. Thus, when compared to irrigated wheat production, the dryland wheat production is a more sustained production. Additionally, it was found that renewable energy had larger share of total inputted energy in dryland compared to irrigated wheat production (table 4). In dryland wheat production, the average of nonrenewable and renewable wheat production was 11344 and 3631 MJ ha^{-1} and in irrigated wheat production it was 45718.7 and 9245.2 MJ ha^{-1} consequently. The major reason for higher nonrenewable energy usage in irrigated wheat production was electricity and diesel fuels (Mondani et al. 2017).

GHG in dryland and irrigated wheat production

The outcome of GHG analysis done in dryland and irrigated wheat production in all five climatic areas are shown in table 5 and table 6. The mean carbon-dioxide discharge in dryland wheat production was 370.5 kg CO2-eq t^{-1} and 548.2 kg CO2-eq ha^{-1} and it was 520.62 kg CO2-eq t^{-1} and 2986.71 kg CO_2-eq ha^{-1} for irrigated wheat production. The reason behind more CO2 discharge in irrigated wheat production is higher overall energy usage of irrigated wheat production system. It can be said that diesel fuels had highest share of GHG discharges compared to other emitters in irrigated wheat production.

Diesel fuels were mostly consumed in tillage operation compared to other agricultural operations. Thus, in a wheat production system approaches such as using chisel plow instead of common plow, carrying out tillage operations in an appropriate soil moisture, modification of ordinary tillage to no tillage or at least minimum tillage, and reducing or removing summer fallow (weed management) can be utilized to reduce diesel fuel usage (Dyer and Desjardins 2003). Other studies have also pointed out the importance of diesel fuel usage in overall GHG. According to other studies, total amount of GHG was measured at 1171.1 kg CO2-eq ha^{-1}. In another study Zafiriou et al. (2012) showed that among all agriculture related productions, productions that have lower input will have less inputted energy and less GHG such as organic farming (Zafiriou et al. 2012).

As of 2019, Iran is the eighth GHG emitter with a large portion of Iran's GHG coming from agricultural operations (Fallahi and Hekmati Farid 2013). Policies of restricting the non-renewable energy overuse can also noticeably reduce GHG (Asgharipour, Mondani, and Riahinia 2012). Other studies conducted in regards of GHG showed that in Iran, wheat production discharges 474 and 173 CO2e t-1. Potato production in city of Fereydunshahr in Iran contributed to 116.4 kg CO_2e t-1 of the total GHG emissions (Khoshnevisan et al. 2014; Soltani et al. 2013). The main reason for GHG in Fereydunshahr was electricity with 97.4% of total GWP. Highest amounts of GHG in Iran comes from irrigation and electricity production (Khoshnevisan et al. 2014). Generating electricity emits large amount of CO_2 and N_2O. To achieve less GHG, using renewable energies such as wind power and utilization of efficient water pumps in irrigation can yield desirable results. Moreover, sustained and environmentally friendly wheat production can be obtained through usage of integrated farming methods due to lesser energy consumption.

Table 5. inputted energy GHG for dryland and irrigated wheat production (kg CO_2-eq ha^{-1}).

	Irrigated	Dryland
1. Machinery	135.1	68.5
2. Diesel fuel	1376.8	398.8
3. Fertilizers		
- Nitrogen	114.3	40.9
- Phosphate	8.9	4.71
- Potassium	2.91	-
4. FYM	227.9	-
5. Biocides		
- Herbicide	13.4	2.4
- Insecticide	5.1	3.3
- Fungicide	6.9	2.01
6. Electricity	1095.4	-
Total	2986.71	520.62

Table 6. GHG in diverse bases for dryland and irrigated wheat production.

Parameters	Irrigated	Dryland
per unit area (kg CO2-eq ha^{-1})	2986.71	520.62
per unit weight (kg CO2-eq t^{-1})	620.8	370.5
per unit energy input (kg CO2-eq MJ^{-1})	57.9	33.4
per unit energy output (kg CO2-eq MJ^{-1})	19.5	8.9

Conclusion

The main idea behind this research was to assess the relationship between energy usage and GHG of inputs in dryland and irrigated wheat production in five different climatic areas in Ardabil province of Iran. Via utilization of random sampling approach, 276 farms were analyzed and the required data was gathered from those farms (134 dryland production farms and 142 irrigated farms). The outcome of that study showed that the nonrenewable and direct energy in an irrigated wheat farm was noticeably higher compared to dryland wheat farms, which was because of farmyard manure usage, water used for irrigation and electricity usage in irrigated wheat production. This means that dryland wheat production system is a more sustained form of production. Additionally, reducing usage of diesel fuels, chemicals and fertilizers were vital for better management of energy. Improving tillage might also be handy for reducing diesel fuel consumption (Asgharipour, Mousavinik, and Enayat 2016a; Mondani et al. 2017).

The mean CO2 discharge for dryland wheat production was 370.5 kg CO_2-eq t^{-1} and 520.62 kg CO2-eq ha^{-1} and for irrigated wheat production it was 620.8 kg CO_2-eq t^{-1} and 2986.71 kg CO_2-eq ha^{-1}. Higher inputted energy in irrigated farms were the main reason for more CO2 discharge. In irrigated wheat production, diesel fuels were measured to be highest GHG emitters followed by electricity in second place, farmyard manure, machinery usage, and finally chemical fertilizers. The GHG discharge order

in dryland wheat production from highest to lowest was diesel fuels, machinery, and chemical fertilizers.
In accordance to the outcome of this study, dryland wheat production needed lesser energy input, thus it had lower GHG compared to irrigated wheat production. Additionally, wheat cultivation in appropriate climatic areas led to lower energy usage and GHG, consequently reducing GWP and atmosphere pollutions. Therefore, it can be said that dryland wheat production is a cleaner production system compared to irrigated wheat production in terms of GHG and energy usage. Irrigated wheat production had better grain and straw yields compared to that of dryland wheat production but it also had higher GHG. However, it can be suggested that for wheat production, utilization of solar or wind energy for water pumps, using biofertilizers and biopesticides can be impactful in energy usage reduction. Additionally, these actions can also be taken at an irrigated wheat production farm to decrease GHG especially in arid and warm climatic areas. In addition, for reduction of GHG in irrigated wheat production, it can be said that utilization of more sustainable cultivation methods i.e. lesser water input via adjusting planting date in accordance to rainfall seasons, soil fertility enhancement via appropriate crop rotation method, machinery and diesel fuel usage reduction using conserving tillage operation system can prove beneficial.

Conflict of interest

The authors declare that they have no conflict of interest.

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