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Modelling of Greenhouse Gas Emissions from Wheat Production in Irrigated and Rain-Fed Systems in Khorasan Razavi Province, Iran

Seyed Masoud Motamedolshariati [1]***, Hassan Sadrnia*** [2]****, Mohammad Hossein Aghkhani*** [3] ***and Mehdi Khojastehpour*** [2]

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Abstract

Agriculture has a key role in greenhouse gas emissions. As such, the present study aimed to evaluate the greenhouse gas emissions from wheat production in irrigated and rain-fed systems. The primary data were collected from 116 wheat farmers. The results showed that the total greenhouse gas emissions from wheat production in irrigated and rain-fed systems were 637.8 and 65.12 kgCO_{2eq}, respectively. The diesel fuel was the largest contributor to the total greenhouse gas emissions in irrigated systems with the share of 33%. Moreover, these inputs accounted for the highest share of greenhouse gas emissions in rain-fed system. The results of Cobb-Douglas model highlighted that the effects of inputs, including machinery, diesel fuel, electricity, and farmyard manure were positive on the yield in irrigated systems. However, the effect of chemical fertilizer and biocide inputs was negative on wheat yield. On the other hand, the effects of all inputs were positive on wheat yield in rain-fed system. The results of the sensitivity analysis showed that one kg increase in greenhouse gas emissions from chemical fertilizer and biocide would result in 0.28 and 0.15 kg loss of yield, respectively.

Keywords:
carbon dioxide, diesel fuel, environment, greenhouse gas emissions, modelling

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[1] *Former M.Sc. Student, Department of Biosystems Engineering, Ferdowsi University of Mashhad, International Campus, Mashhad, Iran*
[2] *Associate Professor, Department of Biosystems Engineering, Ferdowsi University of Mashhad, Mashhad, Iran*
[3] *Professor, Department of Biosystems Engineering, Ferdowsi University of Mashhad, Mashhad, Iran*
* *Corresponding author's email: hassan.sadrnia@um.ac.ir*

INTRODUCTION

Management of the energy resources in the agricultural sector is a reall challenge, and there is considerable potential for the use of renewable energy resources. To optimize food production efficiency, research is needed to investigate the environmental impacts of agricultural production so as to achieve sustainable development. Increased level of mechanization and the use of fossil fuels have caused greenhouse gas (GHG) emissions where their management poses a serious challenge (Liang et al., 2013; Nikkhah et al., 2015a). Agriculture is one of the main sources of GHG emissions such as CO_2, CH_4 and N_2O (Van der Maas et al., 2009; Nikkhah et al., 2015b; Soltanali et al., 2015). It is necessary to evaluate environmental impacts of different sectors of agriculture.

Several research studies have been conducted on GHG emissions in crop production systems in Iran. GHG emissions from corn cultivation was investigated, and the authors reported that the highest share of GHG emissions from corn production in Karaj city of Iran belonged to machinery (74%) followed by diesel fuel (22%) (Pishgar-Komleh et al., 2011).

There have been some studies on GHG emissions from wheat production. For example, Khoshnevisan et al. (2013) showed that the total GHG emissions from wheat production were 2712 $kgCO_{2eq}$ ha^{-1} in Isfahan Province, Iran. Moreover, the greatest share of GHG emissions belonged to the electricity followed by diesel fuel. Soltani et al. (2013) showed that the average of GHG emissions from wheat production was 291 to 11137 $kgCO_{2eq}$ ha^{-1} in Goelestan Province, Iran. In yet another study, Mirhaji et al. (2013) evaluated the environmental impacts of wheat production in the Marvdasht region of Iran using Life Cycle Assessment (LCA) methodology. They claimed that the eutrophication impact category had the largest negative impacts on the environment. GHG emissions of low- and high-input wheat production systems in Western Iran were evaluated, and it was found that the highest share of GHG emissions for low and high input wheat production systems were related to N fertilizer (32%) and electricity (36%), respectively. It was also shown that one hectare of the high-input system will produce 17 times as great greenhouse effect as low-input systems (Yousefi et al., 2016).

The sustainable production of wheat in Khorasan Razavi Province of Iran requires the consideration of environmental management in the production systems. However, to the best knowledge of the authors' knowledge, no previous analytical work has been reported on the environmental impacts of wheat production in that province. Therefore, the aim of the present study was to model the GHG emissions from wheat production in irrigated and rain-fed systems in Khorasan Razavi Province.

MATERIALS AND METHODS

The study area and data collection

The study was conducted in the Sarakhs region of the Khorasan Razavi Province, Iran. The sample size was calculated using the Cochran method (Snedecor & Cochran, 1980):

$$n=(N(s\times t)^2)/((N-1)\,d^2+(s\times t)^2) \tag{1}$$

$$d=(t\times s)/\sqrt{n} \tag{2}$$

where, n = sample size, N = number of holdings in the target population, t = the confidence coefficient (1.96), s = the variance, and d = precision (Fallahi et al., 2016). Based on this calculation, data were collected from 116 farmers using a questionnaire administered face-to-face in 2012-2013. Each farmer was asked to detail activities as inputs to wheat production recorded as machinery use (hr), diesel fuel (l), chemical fertilizer (kg), and biocides (kg), and yield (kg) as the output.

GHG emissions evaluation

The GHG emissions from wheat production were determined by multiplying the input activity data by an emission factor (see Table 1) (Khojastehpour et al., 2015). The CO_2 emission from machinery contributes to the emissions from manufacturing and the use of these inputs in the farm (Firouzi et al., 2016).

GHG *emissions modeling*

The Cobbe-Douglas model was then used to find the effect of GHG emissions on the yield to produce wheat in the region (Royan et al., 2012):

$$Lny_i = a_0 + \sum_{j=1}^{n} \alpha_j \ln(x_{ij}) + e_i = 1,2,\dots,n \qquad (1)$$

where, y_i denotes the yield of the i^{th} farmer; x_{ij} denoteseach of the inputs used in the production process (units as noted above); the constant a_j is the coefficients of inputs which are estimated from the model, and e_i is an error term. With this assumption, yield function of energy inputs, Eq. (3), can be expanded to Eq. (4) (Soltanali et al., 2016):

$$Lny_i = a_0 + \alpha_1 lnx_1 + \alpha_2 lnx_2 + \alpha_3 lnx_3 + \alpha_4 lnx_4 + \alpha_5 lnx_5 + \alpha_6 lnx_6 + e_i \qquad (4)$$

where, x_1, x_2, x_3, x_4, x_5, and x_6 are the energies of seed, human labor, machinery, diesel fueled, chemical fertilizer, and biocide, respectively. The impact of the GHG emissions on the output yield was quantified by using the standard beta. Finally, the sensitivity of yield in the region to GHG emissions was investigated using the marginal physical productivity (MPP) method, which shows the change in the output for one unit change in a given input, keeping all other factors constant (Pishgar-Komleh et al., 2013; Nikkhah et al., 2016). The MPP of the various inputs was calculated by (Rafiee et al., 2010):

$$MPP_{xj} = GM(Y)/GM(X_{ij}) \times \alpha_{ij} \qquad (5)$$

where, MPP_{ij} is the marginal physical productivity of j^{th} input; α_j is the regression coefficient of jth input; $GM\ (Y)$ is the geometric mean of the yield, and $GM\ (X_j)$ denotes the geometric mean of the j^{th} GHGinput on per hectare basis (Mobtaker et al., 2012).

RESULTS AND DISCUSSION

GHG *emissions results*

Table 2 shows the GHG emissions of wheat

Table 1

Greenhouse Gas Emissions Coefficients

Inputs	Unit	(Kg CO_{2eq} unit^{-1})	Reference
Machinery	MJ	0.071	(Dyer & Desjardins, 2006)
Diesel fuel	Lit	2.76	(Dyer & Desjardins, 2003)
Chemical Fertilizer			
(N)	Kg	1.3	(Lal, 2004)
(P_2O_5)	Kg	0.2	(Lal, 2004)
(K_2O)	Kg	0.2	(Lal, 2004)
Biocide			
Fungicides	Kg	3.9	(Lal, 2004)
Insecticides	Kg	5.1	(Lal, 2004)
Herbicides	Kg	6.3	(Lal, 2004)

Table 2

GHG Emissions from Wheat Production in Khorasan Razavi Province, Iran

Inputs	Production systems			
	Irrigated		Rain-fed	
	Average (kgCO_{2eq}. ha^{-1})	Standard deviation	Average (kgCO_{2eq}. ha^{-1})	Standard deviation
Chemical Fertilizers	63.79	57.00		
Nitrogen (P_2O_5)	56.34	49.92		
Phosphorus	7.46	9.18		
Electricity	75.84	69.02		
Biocide	6.14	2.92		
Machinery	154.91	103.89	14.76	3.98
Diesel fuel	207.80	56.54	50.35	19.12
Farmyard manure	129.32	103.89		
Total GHG emissions	637.80	303.32	65.12	29.83

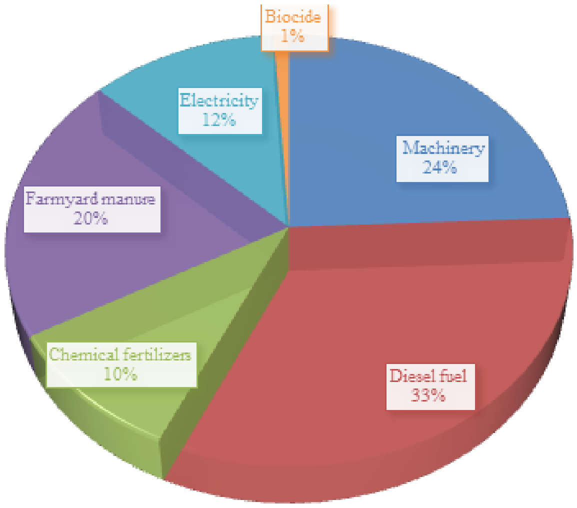

Figure 1. The share of energy inputs for wheat production in irrigated system in Khorasan Razavi Province, Iran

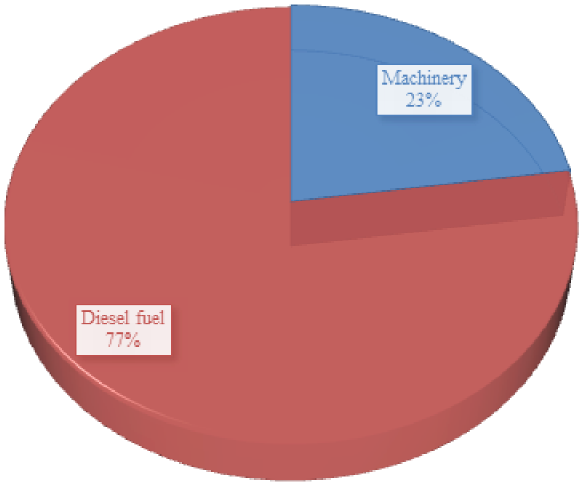

Figure 2. The share of energy inputs for wheat production in rain-fed system in Khorasan Razavi Province, Iran

production in irrigated and rain-fed systems in Khorasan Razavi Province, Iran. GHG emission of the diesel fuel was 207.80 kgCO$_{2eq}$ ha^{-1}. The diesel fuel had the highest share (33%) in the total GHG emission from wheat production in irrigated systems in Khorasan Razavi Province (see Figure 1). The emission of machinery accounted for 24% of total emissions. The amount of GHG emissions from this input of wheat production was 154.91 kgCO$_{2eq}$ ha^{-1} (see Table 2). Diesel fuel and chemical fertilizer had the highest GHG emissions in wheat and potato production (Soltani et al., 2013; Pishgar-Komleh et al., 2012a). GHG emissions from chemical fertilizer were 63.79 kgCO$_{2eq}$ ha^{-1}.

GHG emission from the diesel fuel in wheat production in rain-fed system was 50.35 kg CO$_{2eq}$ ha^{-1}. The diesel fuel had the highest share (77%) in the total GHG emission from wheat production in rain-fed system in Khorasan Razavi Province (see Figure 2). The emission of machinery accounted for 23% of total emissions. The amount of GHG emissions from this input of wheat production was 14.76 kgCO$_{2eq}$ ha^{-1} (see Table 2).

Total GHG emission from wheat production in irrigated and rain-fed systems were obtained as 637.80 and 65.12 kgCO$_{2eq}$ ha^{-1}, respectively (see Table 2). It means that the GHG emissions from wheat production in an irrigated system were higher than that of rain-fed system. Other researchers reported the total GHG emissions as 1195 kgCO$_{2eq}$ ha^{-1} forcotton and 993 kgCO$_{2eq}$ ha^{-1} for potato (Pishgar-Komleh et al., 2012a; Pishgar-Komleh et al., 2012b).

Table 3
Estimation of the Effect of GHGE Missions on Irrigated Wheat Yield in Khorasan Razavi, Iran

	Coefficient	t-ratio	p-value	MPP
Model: $Lny_i = a_0 + \alpha_1 lnx_1 + \alpha_2 lnx_2 + \alpha_3 lnx_3 + \alpha_4 lnx_4 + \alpha_5 lnx_5 + \alpha_6 lnx_6 + e_i$				
Machinery	0.041	1.26	0.141	0.0126
Diesel fuel	0.033	1.12	0.139	0.108
Chemical Fertilizers	-0.902	-2.06	0.019	-0.283
Electricity	0.932	1.54	0.033	0.157
Biocide	-0.054	-4.26	0.009	-0.146
Farmyard manure	0.012	1.14	0.133	0.151
R^2	0.77			
R^2_{Adj}	0.71			
Durbin Watson	2.01			
Return to scale	0.06			

Table 4
Estimation of the Effect of GHG Emissions on Rain-Fed Wheat Yield in Khorasan Razavi, Iran

	Coefficient	t-ratio	p-value	MPP
Model: $Lny_i = a_0 + \alpha_1 lnx_1 + \alpha_2 lnx_2 + e_i$				
Machinery	0.39	2.33	0.03	0.121
Diesel fuel	0.016	0.93	0.238	0.090
R^2	0.71			
R^2_{Adj}	0.68			
Durbin Watson	2.12			
Return to scale	0.41			

Modeling of GHG emissions

The results of the Cobb-Douglas model showed that the impacts of GHG emissions from machinery, diesel fuel, electricity, and farmyard manure on irrigated wheat yield were positive, while the impacts of GHG emissions from the chemical fertilizers and biocide were negative (see Table 3). The results of sensitivity analysis revealed that one kgincrease in GHG emissions from machinery, diesel fuel, chemical fertilizers, electricity, biocides, and farmyard manure changed the yield by 0.0126, 0.108, -0.283, 0.157, -0.146 and 0.151 kg, respectively.

Table 4 displays the estimation of the effect of GHG emissions on rain-fed wheat yield in Khorasan Razavi, Iran. The results of the Cobb-Douglas model showed that the impacts of GHG emissions of machinery and diesel fuel were positive on wheat yield. The results of sensitivity analysis indicated that one kg increase in GHG emissions from machinery and diesel fuel changed the yield by 0.121 and 0.090 kg, respectively.

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