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Environmental and Economic Sustainability Assessment of Rainfed Agro-Systems in Northern Iran

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ABSTRACT

Environmental and economic aspects are two remarkable pillars toward a sustainable agro-system. Accordingly, this study aimed to assess the sustainability of autumn rainfed agro-systems in northern Iran by the Eco-Efficiency (EF) indicator. The data of the production processes of wheat, barley, canola, and triticale were collected in the three crop years of 2016-2019. Results indicated that the canola production system with 720 $kgCO_{2eq}$ ha^{-1} had the highest greenhouse gas (GHG) emissions; however, wheat with 604 $kgCO_{2eq}$ ha^{-1} was attributed to the lowest GHG emissions. The results of the economic analysis also highlighted that the barley production system had the lowest while the canola production system had the highest production costs. The canola production system had the highest profitability, while the barley production system had the lowest in terms of net income and average benefit to cost ratio indicators. The EF indicator for wheat, barley, canola, and triticale was determined to be 1.4, 0.6, 1.8, and 1.1, respectively, indicating the highest EF value for the canola production system.

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1. INTRODUCTION

The agricultural sector is the largest economic sector in the world and its growth and development are of great importance not only from an economic viewpoint but also in various social and environmental dimensions. In this regard, the analysis of agricultural systems can have a significant role in reducing the destructive impacts on the environment and, thus, achieving sustainable agriculture [1]. Today, the growing trend of GHG emissions arising from burning fossil fuels has led to greater attention to reduction of energy consumption in various fields [2]. Therefore, considering environmental issues has become one of the main components in global planning and the most critical factor in and prerequisite for many activities in the world [3, 4]. In addition to environmental issues, increasing economic productivity is also essential to achieving greater profits. In this regard, paying attention to the profitability of production in line with environmental issues leads the EF indicator to be defined. The EF with the definition of "The ratio of product value to environmental issues" is considered a useful tool for improving economic and environmental sustainability simultaneously [5]. The EF includes strategies that both increase the efficiency of energy consumption and reduce the production costs [6]. In this regard, using the indicator can be a proper criterion to investigate the sustainability of agricultural production [7, 8].

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Due to the climatic conditions of Iran, about 75 % of agricultural lands (11 million hectares) are rainfed. Mazandaran province in northern Iran, having 83,000 hectares of rainfed farms, is known as one of the major production regions of rainfed crops. The most important rainfed crops in the province include wheat, barley, canola, triticale, soybeans, and vegetables and the four autumn crops, i.e., wheat, barley, canola, and triticale with a total area of 71,000 hectares, have the highest area among rainfed crops in the province [9]. Given the importance of producing rainfed crops to increase income and meet food needs, improving these production systems can be essential. In other words, the growing trend of consuming energy and chemical inputs per unit area in recent years has increased the amount of pollutants emitted to the environment in the agro-systems. Since optimal input consumption is a primary aim in the development of sustainable agriculture, it is vital to consider the consumption of input energies in agricultural production processes [10]. Therefore, various studies have been conducted recently to examine agricultural inputs and production costs of various crops in Iran and the world. An economic and environmental study of a wheat production system in western Iran claimed that net income and benefit to cost ratio were 488 \$ ha^{-1} and 2.33, respectively. Moreover, the highest GHG emissions belonged to electricity and nitrogen fertilizer [11]. The economic analysis of wheat production in Turkey claimed that the benefit to cost ratio was 1.2 and agricultural machinery and chemical fertilizers attended to the highest contribution to variable costs [12]. The study of canola production in

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Golestan province approved that the chemical fertilizers and diesel fuel had the highest contributions to GHG emissions with 51.23 % and 30.16 %, respectively [13]. Another study on wheat, barley, canola, soybean, paddy, and corn silage crops in northern Iran pointed out that three crops of canola, barley, and wheat had the lowest GHG emissions with 1,064, 1,106, and 1,171 kgCO_{2eq} ha^{-1}, respectively, and paddy with 6,094 kgCO_{2eq} ha^{-1} had the highest GHG emissions [14].

Various studies have also focused on evaluating the EF value in agricultural production. For instance, the results of a study on the EF value of paddy production in Thailand indicated that under equal income conditions, GHG emissions in the rainfed system were lower than that in the irrigated system [15]. In another research in Italy, the results of a study on the EF value of rapeseed and sunflower production highlighted that the EF value of rapeseed production was lower than sunflower. The results also revealed that sunflower production was more environmentally friendly than rapeseed [16]. It was also stated that in wheat production in Japan, nitrogen fertilizer was the main contributor to increasing the EF value and, thus, to sustainable development of wheat production [17]. In another study, an assessment of the EF value of tangerine production in northern Iran showed that the net income was 2.18 $ kgCO_{2eq}^{-1}. It was also stated that chemical fertilizers had the highest contribution to both environmental and economic sustainability of tangerine production [18].

This study aimed to investigate the sustainability of autumn rainfed agro-systems in northern Iran using the Eco-Efficiency (EF) indicator. This indicator has recently become a key tool for assessing different agricultural systems in Iran and across the world, due to its potential ability to quantify and integrate two major pillars of sustainable development, i.e., economic and environmental aspects. This point can lead to providing a powerful tool for investigating and comparing various crops in terms of how it is possible to make a balance between economic outputs and environmental effects of an agricultural system. However, according to the literature review, no research has been done so far on the sustainability of autumn rainfed agro-systems from environmental and economic points of view. Therefore, although different evaluation indices can be considered to estimate the EF of a crop production system, this study followed the procedure proposed by previous studies as in [18] due to the availability and simplicity of data collection. Besides, unlike other studies, three-year classified data have been used in this research, allowing for the investigation of the inputs flows over the time. Therefore, the main objectives of this research were to do (i) economic analysis and determine the economic indicators in the production of autumn rainfed crops including wheat, barley, canola, and triticale, (ii) conduct environmental analysis of autumn rainfed crops production, and finally (iii) compare the EF values of these crops to investigate the overall sustainability of the production systems.

2. METHOD

2.1. Data collection and study area

The study area was Mazandaran province located in northern Iran. Dasht-E Naz Sari Agricultural Company is of the main agricultural companies in northern Iran, which is located in Mazandaran with an area under cultivation of about 3,900 hectares. Irrigated and rainfed systems are being used for crop production in this company. Given the large area under cultivation of autumn rainfed crops in this company and also access to accurate data about using inputs, this company was selected to be the study area. Since the main rainfed systems of this company are located in Galugah County in this province, this region was selected as the study area. The mean values of some climatic parameters of Galugah County during 2006-2020 are shown in Table 1. Four major rainfed crops in this region, i.e., wheat, barley, canola, and triticale, were investigated during three crops years from 2017 to 2019. The total areas occupied by the four crops were 800, 770, and 685 ha in these three years, respectively, in the study area. In this company, the crops are cultivated in several smaller fields with different sizes. Accordingly, the required data were collected from all fields in each year and the average consumption of inputs was expressed per hectare (Table 2).

Table 1. Climatic conditions of Galugah, on average

Daily temperature (°C)	Annual precipitation (mm)	Total rainy days (day)	Total sunny hours (h)	Air relative humidity (%)	Annual evaporation (mm)
17.7	617	91	1962	75	1148

Table 2. Consumed inputs in wheat, barley, canola, and triticale production systems per unit area

Variables	Wheat (Unit ha^{-1})				Barley (Unit ha^{-1})		
	1st year (2016-2017)	2nd year (2017-2018)	3rd year (2018-2019)		1st year (2016-2017)	2nd year (2017-2018)	3rd year (2018-2019)
Machinery (h)	7.32	6.51	6.15		7.89	8.99	7.78
Diesel fuel (l)	94.08	92.40	98.54		88.42	107.10	98.00
Biocides (kg)	3.72	2.88	3.92		2.5	5.78	6.18
Chemical fertilizers (kg)	291.80	382.83	275.70		319.30	343.75	203.06
Manure (kg)	5040.00	5016.00	5038.50		4970.00	5000.00	5277.00
Seed (kg)	259.44	261.73	252.12		200.7	196.74	240.22
Human labor (h)	7.20	6.44	7.88		7.16	9.39	7.22
Output (kg)	2786.88	4057.73	3586.35		1587.34	3707.55	2164.11
Total area (ha)	250	300	260		342	200	180
	Canola (Unit ha^{-1})				Triticale (Unit ha^{-1})		
Machinery (h)	9.89	9.52	8.76		6.78	5.58	6.17
Diesel fuel (l)	121.33	120.40	118.05		106.78	104.30	100.80

Biocides (kg)	4.35	3.26	7.81		3.00	5.06	6.14
Chemical fertilizers (kg)	610.56	623.33	478.51		356.36	275.42	426.67
Manure (kg)	5000.00	4933.00	4865.00		5085.00	5000.00	5000.00
Seed (kg)	7.44	7.57	5.54		205.00	250.25	231.50
Human labor (h)	12.22	13.82	12.43		6.78	7.30	6.67
Output (kg)	2299.89	2754.67	2525.89		3065.59	3382.83	4168.00
Total area (ha)	90	150	185		118	120	60

2.2. GHG emissions analysis

The GHG emissions of the investigated systems were estimated by multiplying the value of inputs consumed in each system by its emission coefficient (Table 3). The investigated inputs were diesel fuel, manure, agricultural machinery, chemical fertilizers, and biocides.

Table 3. GHG emission coefficient of consumed inputs

Inputs	Unit	GHG emissions coefficient ($kgCO_{2eq}$)	Reference
Agricultural machinery	MJ	0.071	[19]
Diesel fuel	L	2.76	[20]
Biocides			
(a) Herbicides	kg	6.3	[21]
(b) Pesticides	kg	5.1	[21]
(c) Fungicides	kg	3.9	[21]
Chemical fertilizers			
(a) Nitrogen	kg	0.09	[22]
(b) Phosphate	kg	0.15	[22]
(c) Potassium	kg	0.51	[22]
Manure	kg	0.0462	[23]

The GHG emission (G_M) of agricultural machines was estimated in terms of the energy value of this input (Eq. 1). Accordingly, G_M can be obtained from the machine working hours (H_M) and the energy equivalent coefficient of machines (0.62 MJ h^{-1}) [24] and GHG emission coefficient (C_M) are presented in Table 2. The GHG emissions of other inputs were determined using Eq. 2. In this equation, G_I and C_I donate the values and coefficients of GHG emissions, respectively, and W refers to the inputs used in the production process. W_I included electricity (kWh), diesel fuel (L), and chemical fertilizers (kg), biocides (kg), and manure (kg) [25]. Various biocides and chemical fertilizers used in the production process can be attended at different energy levels. Therefore, to obtain GHG emissions from the inputs, biocides were divided into three sub-groups, i.e., herbicides, fungicides, and insecticides. Similarly, chemical fertilizers were divided into three sub-groups of nitrogen, phosphorus, and potash [21].

$$G_M = 0.62 \times H_M \times C_M \quad (1)$$

$$G_I = W_I \times C_I \quad (2)$$

2.3. Economic analysis

The economic analysis of autumn rainfed agro-systems in Mazandaran province was conducted based on the amount of consumed inputs for each crop (wheat, barley, canola, and triticale). The total production costs and the total production value for each crop were computed per unit area. The economic indicators, i.e., gross income, net income, benefit to cost ratio, and economic productivity associated with each crop were estimated (Eqs. (3) to (6)) and compared [26-28].

$$\text{Gross income} = \text{Total production value} \left(\$\ ha^{-1}\right) - \text{Variable costs} (\$\ ha^{-1}) \quad (3)$$

$$\text{Net income} = \text{Total production value} \left(\$\ ha^{-1}\right) - \text{Total production cost} (\$\ ha^{-1}) \quad (4)$$

$$\text{Benefit to cost ratio} = \frac{\text{Total production value} \left(\$\ ha^{-1}\right)}{\text{Total production cost} \left(\$\ ha^{-1}\right)} \quad (5)$$

$$\text{Economic productivity} = \frac{\text{Yield} \left(kg\ ha^{-1}\right)}{\text{Total production cost} \left(\$\ ha^{-1}\right)} \quad (6)$$

2.4. EF indicator

The EF is the main indicator for improving both economic and environmental sustainability in agricultural production. In this study, the EF value was determined for investigated agro-systems. The indicator is calculated by dividing the economic output indicator (I_{eco}) to the environmental impact indicator (I_{env}) [29] (Eq. 7). In this regard, economic output and environmental impact indicators were considered to be the net income and GHG emissions in the production process of each crop per unit area, respectively.

$$EF = \frac{I_{eco}}{I_{env}} \quad (7)$$

3. RESULTS AND DISCUSSION

3.1. GHG emission analysis

Table 4 presents the average inputs consumption and the average GHG emissions from investigated agro-systems in Mazandaran province. The average yield of wheat, barley, canola, and triticale was 3,476.99, 2,486.33, 2,526.82, and 3,538.81, respectively, which was remarkably higher than the average yield of these crops in Iran [9]. The total GHG emissions derived from producing wheat, barley, canola, and triticale were found to be 604.34, 619.94, 720.38, and 628.62 $kgCO_{2eq}$ ha^{-1}, respectively, among which canola had the highest GHG emissions, while wheat had the lowest GHG emissions. It can be due to the difference in the amounts of inputs consumption in the investigated agro-systems. Accordingly, results exhibit that chemical fertilizers, particularly nitrogen fertilizers, were the main reason of the higher value of GHG emissions in the canola agro-system. Similar findings were reported in previous studies [13, 30, 31], where the highest GHG emissions of canola production belonged to the chemical fertilizers. The higher consumption of chemical fertilizers in canola production can be associated with higher nutritional needs of the crop. A study on how nitrogen fertilizer can affect seed yield of wheat and canola approved that at a given level of N-fertilizer, the yield of wheat was significantly higher than canola [32]. Another study also claimed that for producing 90 % of the maximum yield, N and k-fertilizer requirements of canola were 26 % and 32 % higher than those of wheat, respectively [33]. However, the excessive use of chemical fertilizers can be managed by replacing bio-sources of nutrition such as crop residues, or manure, as well as applying the optimal level of fertilizers based on the local conditions [34-38]. Gao et al. reported that at similar N levels, manure application sometimes led to greater production of oil content in canola than fertilizers [39]. The contribution of the consumed inputs to GHG emissions is presented in Figure 1. The diesel fuel input was attended to the highest GHG emission rate in four investigated agro-systems, and the highest and lowest GHG emission rates from this input belonged to the canola production process with 331.00 $kgCO_{2eq}$ ha^{-1} and 46 % and wheat production with 262.22 $kgCO_{2eq}$ ha^{-1} and 22.4 %, respectively. The manure input was the second greatest contributor to GHG emissions in all investigated agro-systems. The input had the highest GHG emissions with 234.83 $kgCO_{2eq}$ ha^{-1} in the barley production, while the canola production with 227.89 $kgCO_{2eq}$ ha^{-1} had the lowest emission. According to Figure 1, the two inputs of diesel fuel and manure contributed to 77.6 % to 82.6 % of total GHG emissions, in producing autumn rainfed crops in Mazandaran province. The manure input had a high consumption in autumn rainfed agro-systems in this region, such that, according to Table 2, the average consumption of this input in all investigated agro-systems was about 5,000 kg ha^{-1}. Chemical fertilizers ranked third in GHG emissions in all studied agro-systems. The GHG emission from this input in canola production with 89.77 $kgCO_{2eq}$ ha^{-1} and 12.4 % was the highest and in barley production, with 52.80 $kgCO_{2eq}$ ha^{-1} and 8.5 % was the lowest. In this province, farmers use a combination of manure and chemical fertilizers to feed farms. Therefore, the consumption of chemical fertilizers in the production of rainfed crops in this region was much lower than that in similar studies [11, 40]. Other studies have reported that the simultaneous use of manure and chemical fertilizers can result in a significant reduction in chemical fertilizers consumption [41, 42]. The GHG emissions of the two inputs of agricultural machinery and biocides also were the lowest in the studied agro-systems. According to Table 4, the GHG emissions from consuming these inputs in the canola production were the highest and in the production of triticale and wheat were the lowest. Overall, the results indicated that canola had the highest GHG emissions, while wheat had the lowest GHG emissions among studied crops. Therefore, the GHG emissions from all inputs consumption except manure for canola were higher than those for other investigated agro-systems.

Table 4. Consumed inputs and GHG emissions of autumn rainfed agro-systems

Variables	Consumed inputs (Unit ha^{-1})					GHG emissions ($kgCO_{2eq}$ ha^{-1})			
	Wheat	Barley	Canola	Triticale		Wheat	Barley	Canola	Triticale
Inputs									
Machinery (MJ)	6.66	8.22	9.39	6.18		29.66	36.60	41.80	27.50
Diesel fuel (kg)	95.01	97.84	119.93	103.96		262.22	270.04	331.00	286.93
Biocides (kg)	3.51	4.82	5.14	4.73		19.16	25.68	29.92	25.08
(a) Herbicides	1.94	2.48	3.88	2.37		12.12	15.63	24.42	14.92
(b) Insecticides	0.69	0.78	0.48	0.78		3.51	3.96	2.44	3.99
(c) Fungicides	0.88	1.56	0.78	1.58		3.43	6.09	3.06	6.18
Chemical fertilizers (kg)	316.78	288.70	570.80	352.81		60.84	52.80	89.77	56.81
(a) Nitrogen	169.54	165.77	402.63	215.30		15.26	14.92	36.24	19.38
(b) Phosphorous	81.98	68.94	89.55	90.84		12.30	10.34	13.43	13.63
(c) Potassium	65.26	54.00	78.62	46.67		33.28	27.54	40.10	23.80
Manure (kg)	5031.71	5082.85	4932.73	5028.25		232.46	234.83	227.89	232.31
Seed (kg)	257.76	212.35	6.85	228.92		-	-	-	-
Human labor (h)	7.17	7.92	12.82	6.92		-	-	-	-
Total GHG emissions	-	-	-	-		604.34	619.94	720.38	628.62
Output									
Yield (kg)	3476.99	2486.33	2526.82	3538.81		-	-	-	-

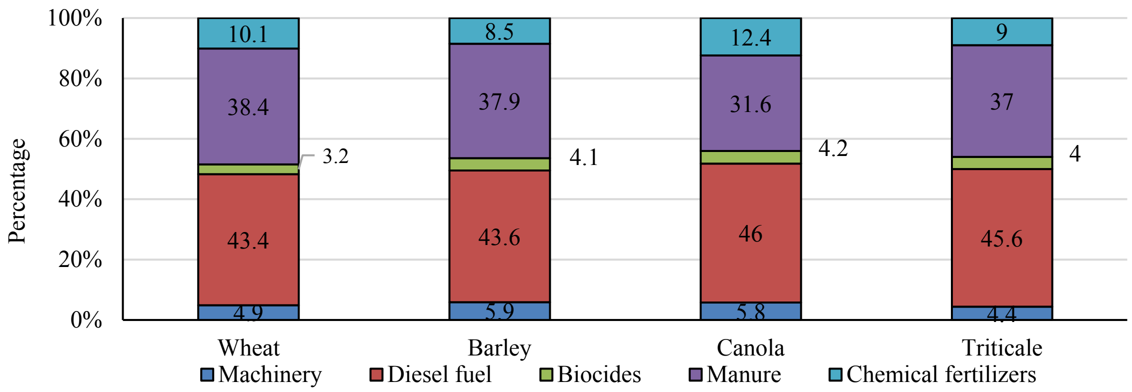


Figure 1. Share of GHG emissions of consumed inputs in wheat, barley, canola, and triticale productions

The GHG emissions from autumn rainfed agro-systems were also investigated in terms of crop years (Figure 2). The results for wheat production revealed that although the total GHG emissions varied over three years, the differences were not significant. According to Figure 2(a), the emissions from all inputs were equal every three years, and only the input of chemical fertilizers in the second year had a higher GHG emission rate than in other years. The results of the study of barley production claimed that the total GHG emissions of the second year (666.2 $kgCO_{2eq}$ ha^{-1}) were estimated significantly higher than in the other two years. According to Figure 2(b) in the second year, GHG emissions of diesel fuel, chemical fertilizers, and agricultural machinery inputs were higher than in the other years. Figure 2(c) depicts the results of studying the canola production, where although the GHG emissions of diesel fuel, manure, and agricultural machinery in the first year were greater than the other years and the total GHG emission in the third year (740.6 $kgCO_{2eq}$ ha^{-1}) was obtained to be more than that in other years. The difference can be associated with the higher GHG emissions of biocides and chemical fertilizers in the third crop year. However, overall, the difference in GHG emissions was not significant in different years. The results of studying the triticale production (Figure 2(d)) also highlighted that although the total GHG emissions were higher in the third year, this difference was not significant. The difference can be associated with the higher GHG emissions of biocides and chemical fertilizers in the third crop year.

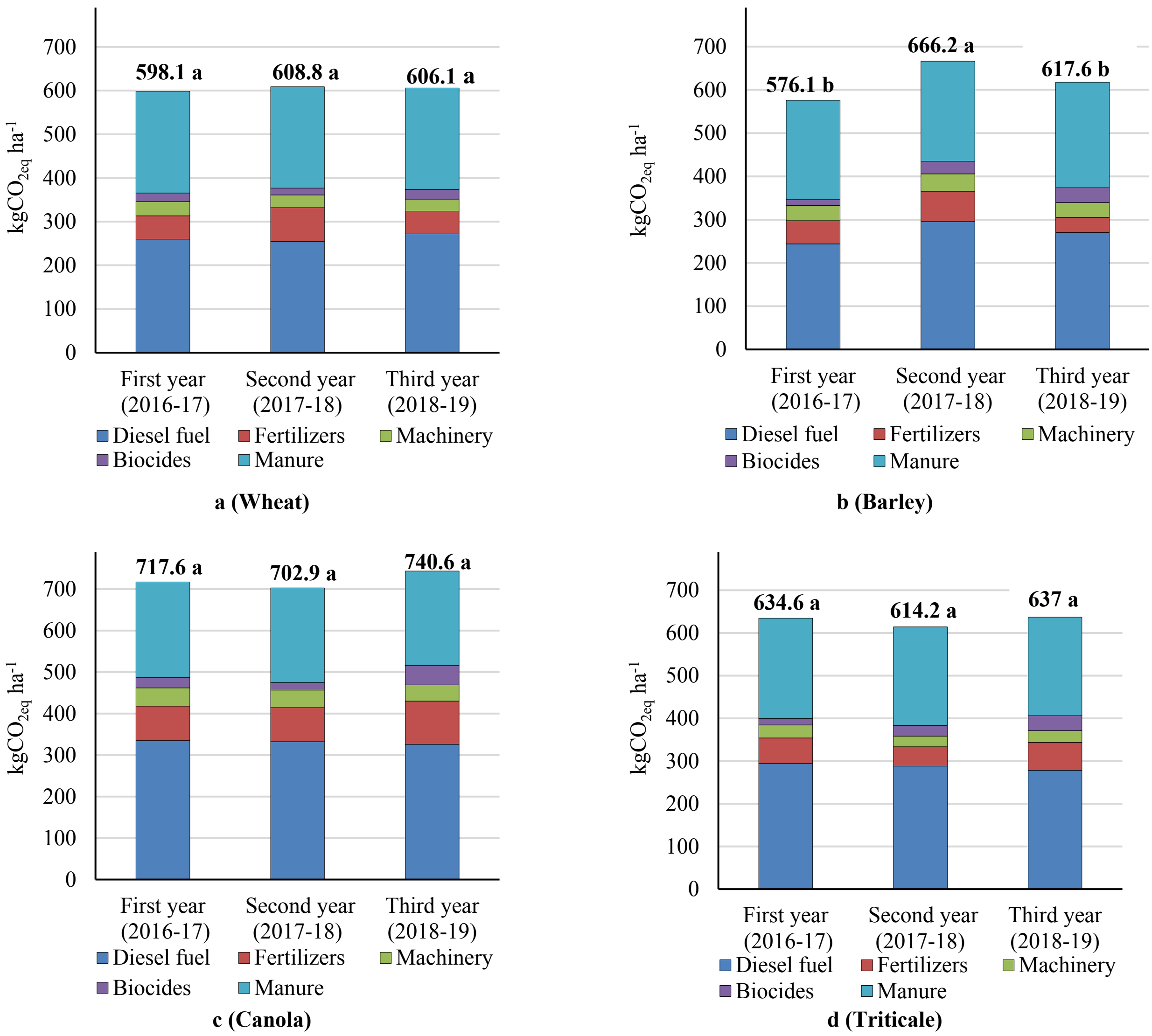


Figure 2. The GHG emissions of consumed inputs in (a) wheat, (b) barley, (c) canola, and (d) triticale production during three crop years (2016-2019) in Mazandaran province

3.2. Economic analysis

Table 5 presents the economic indicators and production costs of autumn rainfed crops in Mazandaran province. The total production costs for wheat, barley, canola, and triticale were 623.20, 596.81, 671.41, and 597.64 \$ ha^{-1}, respectively. Barley had the lowest and canola had the highest production costs. The gross income of producing these crops was found to be 1490.14, 947.17, 1949.26, and 1263.86 \$ ha^{-1}, respectively, in which canola had the highest gross income and the lowest value of the indicator belonged to the barley production system. In general, among the rainfed autumn crops in this region, canola had the highest production costs as well as the highest gross income. The economic analysis of crops in Moghan Plain indicated that canola had the highest production costs and income, while the values for barley were lower than canola and wheat [43].

Figure 3 depicts the contribution of consumed inputs to the production costs for investigated agro-systems. Examining the variable costs revealed that seed, chemical fertilizers, manure, and agricultural machinery were among the costliest inputs in all the investigated agro-systems. In wheat production, seed and manure had the highest costs, with 150.36 and 119.80 $ ha^{-1}, respectively, and with a total share of 51.1 %. In wheat production, the average seed consumption was approximately 258 kg ha^{-1}, which was higher than that of the wheat production systems in other parts of Iran [26, 40]. In barley production, manure input with 121.02 $ ha^{-1} and 23.9 % had the highest production costs. Agricultural machinery and seed inputs with 23.2 % and 18 %, respectively, were among the most expensive inputs in the production. In another study on barley production, it was reported that seed input was one of the most consumed inputs [44]. In canola production, chemical fertilizers with 151.66 $ ha^{-1} and 26.6 % had the highest production costs due to the high consumption of nitrogen fertilizer. Accordingly, the highest costs associated with the chemical fertilizers belonged to the nitrogen fertilizer with 95.86 $ ha^{-1} for the consumption value of 402.63 kg ha^{-1}. The consumption of chemical fertilizers in this study was found to be higher than that in other regions of Iran [13, 45]. In general, the high nutritional needs of canola to nitrogen fertilizer [46] and the semi-mechanized distribution systems of spreading nitrogen fertilizer (using fertilizer broadcaster) in farms increased the consumption of this input. In this regard, by using a proper combination of manure and chemical fertilizers, the consumption of this input can be reduced [42, 47]. In the triticale production system, similar to wheat, the two inputs of manure and seeds with 119.72 and 109.01 $ ha^{-1}, respectively, and with a total share of 45.1 % had the highest production costs.

Biocides, human labor, and diesel fuel were also in the next ranks of production costs for all the investigated crops. Although biocides were responsible for the lowest GHG emissions, their contribution to the production costs was significant due to the high consumption rates of herbicides in all studied agro-systems. In other words, according to Table 5, the cost of herbicides was at least two times higher than that of fungicides and insecticides. The lowest costs also belonged to the diesel fuel. This input was the highest contributor to GHG emissions in all the investigated crops. However, the contribution of diesel fuel to production costs varied from 1.3 to 1.5 % and it results from low price of diesel fuel and consequently, high and overuse of this input in Iran. Similar findings are also reported in previous studies on various crop production systems in the same region [28, 48] (Esmailpour-Troujeni et al., 2018; Mirkarimi et al., 2021).

Assessing the economic indicators revealed that the net income of wheat, barley, canola, and triticale was 866.94, 350.37, 1,277.85, and 666.22 $ ha^{-1}, respectively. The average benefit to cost ratio of these crops was also 2.39, 1.59, 2.90, and 2.11, respectively. The results of these two indicators indicated the high profitability of canola production and the low profitability of barley production. The economic productivity of these crops was also estimated at 5.85, 4.17, 3.76, and 5.92 kg ha^{-1}, respectively, indicating that for every dollar spent on production, more wheat and triticale were produced. Overall, the results of studying economic indicators highlighted that canola and barley had the highest and lowest profitability among autumn rainfed crops, respectively. Unakitan et al. [49] in assessing the canola production in Turkey, reported that the crop production in Turkey was highly profitable. They found the benefit to cost ratio and net income in canola production to be 2.09 and 916.63 $ ha^{-1}, respectively, which was less than that of the current study. Mousavi-Avval et al. [45] in the economic assessment of canola production in three different farm sizes in northern Iran stated that the maximum values of benefit to cost ratio and net incomes were 1.59 and 532.81 $ ha^{-1}, indicating high profitability of canola production.

Table 5. Production costs and economic indicators of wheat, barley, canola, and triticale

Items	Unit	Wheat	Barley	Rapeseed	Triticale
A. Inputs					
1.Machinery	$ ha^{-1}	95.18	117.44	134.12	88.24
2.Human labor	$ ha^{-1}	15.37	16.98	27.48	14.82
3.Ch fertilizers	$ ha^{-1}	89.05	80.09	151.66	96.05
(a) Nitrogen	$ ha^{-1}	40.37	39.47	95.86	51.26
(b)Phosphorous	$ ha^{-1}	25.37	21.34	27.72	28.12
(c) Potassium	$ ha^{-1}	23.31	19.29	28.08	16.67
4.Seed	$ ha^{-1}	150.36	91.01	57.07	109.01
5.Biocides	$ ha^{-1}	51.58	72.25	72.64	71.22
(a) Herbicides	$ ha^{-1}	25.85	33.07	51.68	31.57
(b) Insecticides	$ ha^{-1}	10.00	11.28	6.95	11.35
(c) Fungicides	$ ha^{-1}	15.73	27.89	14.02	28.29
6. manure	$ ha^{-1}	119.80	121.02	117.45	119.72
7.Diesel fuel	$ ha^{-1}	6.79	6.99	8.57	7.43
B. indices					
Variable cost	$ ha^{-1}	528.13	505.77	569.0	506.47
Fixed cost	$ ha^{-1}	95.06	91.04	102.42	91.17
Total cost	$ ha^{-1}	623.20	596.81	671.41	597.64
Sale price	$ kg^{-1}	0.43	0.38	0.77	0.36
production value	$ ha^{-1}	1490.14	947.17	1949.26	1263.86
Benefit to cost ratio	-	2.39	1.59	2.90	2.11
Eco-productivity	kg $$^{-1}$	5.58	4.17	3.76	5.92
Gross income	$ ha^{-1}	962.01	441.41	1380.26	757.39
Net income	$ ha^{-1}	866.94	350.37	1277.85	666.22

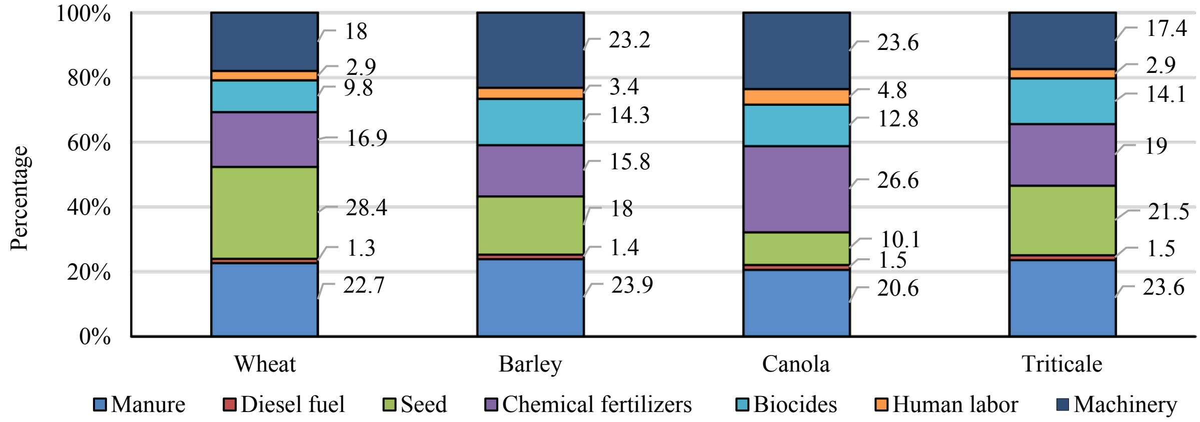
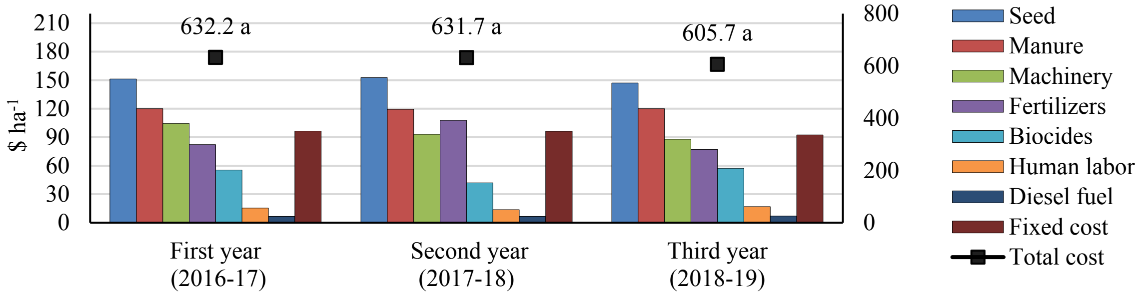
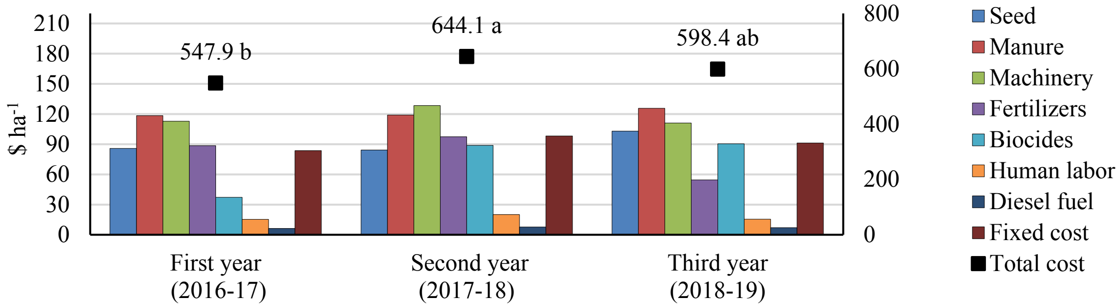


Figure 3. The share of consumed inputs in the average production costs of wheat, barley, canola, and triticale

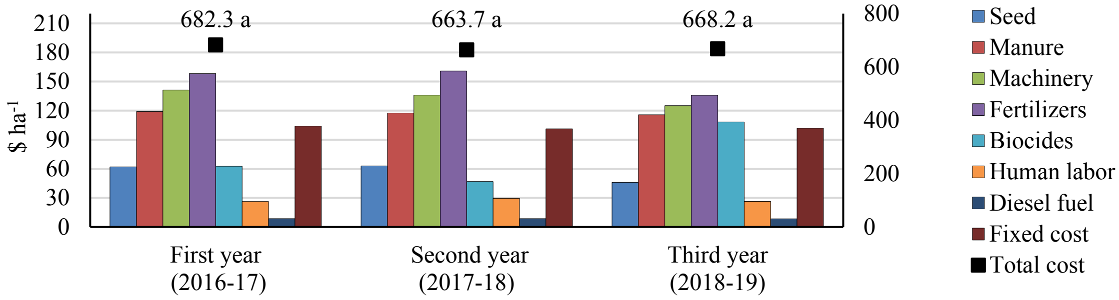
Figure 4 depicts the share of each input in the production cost of autumn rainfed crops in terms of different crop years. In wheat production (Figure 4(a)), however, production costs in the first and second years were higher than in the third year and the differences were not significant. The reason for this difference was the higher cost of two inputs of agricultural machinery and chemical fertilizers, respectively, in the first and second crop years. In barley production (Figure 4(b)), it can be stated that the total production costs for the second year with 644.1 \$ ha^{-1} were significantly higher than the first year with 547.9 \$ ha^{-1}. Therefore, the costs of all inputs, except seed and manure, were higher in the second year than in the first year. According to Figure 4(c), the results of the study on canola revealed that there was no significant difference between production costs in three years and the consumption of inputs in different years was almost equal. The study on triticale also indicated an upward trend in production costs over three years (Figure 4(d)). Thus, total production costs for the third year (639.4 \$ ha^{-1}) were significantly higher than the first year (568.7 \$ ha^{-1}). Overall, the results of the study on production costs in different years pointed out that the two crops of wheat and canola had the least changes in production costs and the two crops of barley, while triticale, had significant changes in production costs.



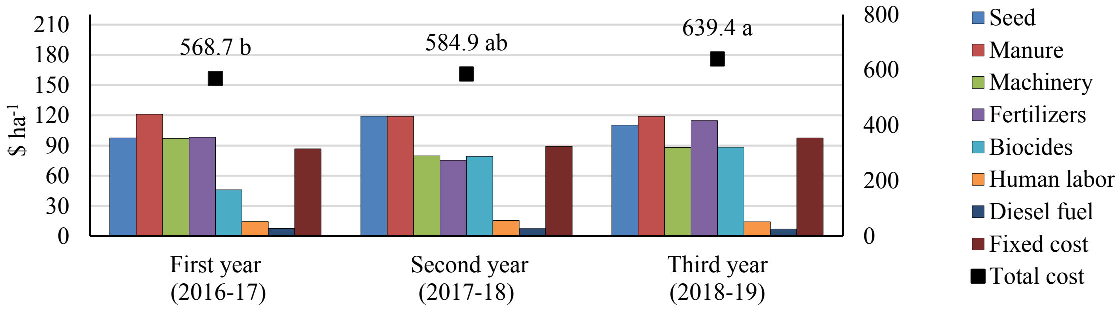
a (Wheat)



b (Barley)



c (Canola)



d (Triticale)

Figure 4. Share of consumed inputs in the production costs of (a) wheat, (b) barley, (c) canola, and (d) triticale

3.3. EF Indicator analysis

Figure 5 presents the EF value of investigated autumn rainfed agro-systems in Mazandaran province. The EF values for producing wheat, barley, canola, and triticale were calculated as 1.43, 0.57, 1.77, and 1.06 \$ $kgCO_{2eq}^{-1}$, respectively, resulting in the highest EF value of canola production. However, GHG emissions from canola production were higher than other crops (according to Table 3), the EF value of canola production was the highest. It can be associated with the higher net income of canola production. According to Table 4, the net income of canola production was about four times higher than that of barley production and about two-fold higher than that of triticale production. In general, by reducing GHG emissions and increasing net income, the EF value could be increased in the production of these crops. In the study of rapeseed and sunflower production in Italy, the maximum values of EF were reported to be 0.82 and 0.30 \$ $kgCO_{2eq}^{-1}$, respectively [50], which was much lower than that of autumn rainfed crops in Mazandaran province. The EF value of sugarcane production in Thailand was determined to be 2.8 \$ $kgCO_{2eq}^{-1}$ [51] and higher than that of the investigated agro-systems in the current research.

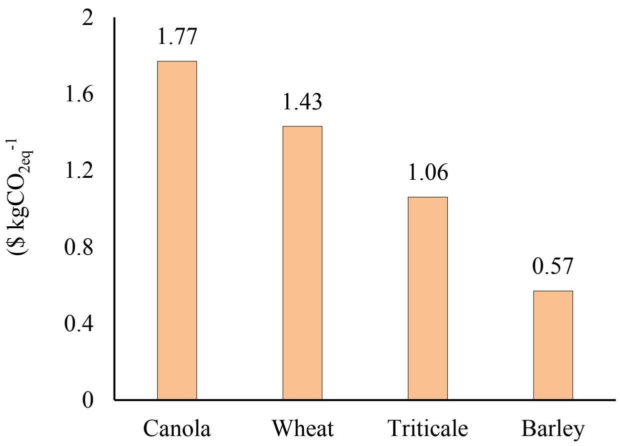


Figure 5. The EF value of wheat, barley, canola, and triticale production systems, on average

The EF value of the investigated agro-systems in terms of different crop years is presented in Table 6. Accordingly, the difference between the EF values in three years was significant for wheat and barley, while it was not significant for canola and triticale in different years. The EF values of wheat production in the second and third years were higher than in the first year, and for barley in the second year was much higher than in the first and third years, which was significant at a 5 % level. In general, the EF values in all investigated agro-systems were higher in the second year than in the first year, which can be due to the weather conditions and the amount of annual rainfall in the region.

Table 6. The EF value of wheat, barley, canola, and triticale production per hectare (\$ $kgCO_{2eq}^{-1}$)

Crop	EF (Based on net income)		
	1st year (2016-2017)	2nd year (2017-2018)	3rd year (2018-2019)
Wheat	0.94^b	1.82^a	1.53^a
Barley	0.10^b	1.15^a	0.37^b
Canola	1.52^a	2.08^a	1.73^a
Triticale	0.83^a	1.01^a	1.33^a

4. CONCLUSIONS

The study investigated the sustainability of autumn rainfed agro-systems (wheat, barley, canola, and triticale) in northern Iran using the EF indicator. The investigated inputs included seed, human labor, manure, diesel fuel, agricultural machinery, chemical fertilizers, and biocides in three crop years of 2016-2019. GHG emissions from inputs were obtained through GHG emission coefficients, and the EF was estimated based on the ratio of the net income indicator to the environmental impact indicator. The total GHG emissions from wheat, barley, canola, and triticale production were determined to be 604.34, 619.94, 720.38, and 628.62 $kgCO_{2eq}$ ha^{-1}, respectively, in which the diesel fuel had the highest GHG emissions in all the investigated agro-systems. In general, canola had the highest GHG emissions, while the lowest GHG emissions belonged to the wheat production system. The GHG emissions from all inputs consumption except manure for canola production were higher than those for other investigated crops production systems. In the wheat and triticale production systems, the semi-mechanized sowing system caused increase in the consumption and cost of seeds, and in the canola production, use of the semi-mechanized system for distributing the nitrogen fertilizer (using fertilizer broadcaster) in farms was the most effective factor in increasing the chemical fertilizers consumption. In determining the economic indicators, the net income of wheat, barley, canola, and triticale production was found to be 866.94, 350.37, 1277.85, and 666.22 \$ ha^{-1}, respectively, and the average benefit to cost ratios of these products were 2.39, 1.59, 2.90, and 2.11, respectively. The results of these two indicators presented high profitability of canola production and low profitability of barley production. The EF values for wheat, barley, canola, and triticale production systems were determined to be 1.43, 0.57, 1.77, and 1.06 \$ $kgCO_{2eq}^{-1}$, respectively, in which canola had the highest EF value. In conclusion, canola can be recommended as the most sustainable crop in terms of economic and environmental points of view. Further research is required to investigate the third pillar of sustainability of the investigated production systems as the social aspect.

5. ACKNOWLEDGEMENT

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