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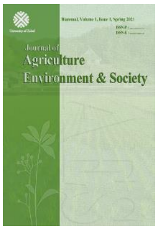

The Effect of crop rotation on energy indices and greenhouse gas emissions in wheat (*Triticum aestivum* L.) and chickpea (*Cicer arietinum*) dryland agroecosystems in Kermanshah region, Iran

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ABSTRACT

The application of appropriate agricultural practices leads to savings in fuel consumption, energy, and a reduction in greenhouse gas emissions. Therefore, this research was conducted to compare wheat-chickpea crop rotation with wheat monoculture in terms of energy indices and amount of greenhouse gas emissions in dryland agroecosystems during 2021. The amounts of inputs consumed and all agricultural operations in the studied agroecosystems from planting to harvesting were calculated through questionnaires and energy analysis. Data analysis included three components: energy inputs, energy outputs, and global warming potential due to greenhouse gas emissions. The results indicated that total energy input for wheat-chickpea rotation and wheat monoculture was 13550.5 and 15106.8 Mj ha^{-1}, respectively. The total energy output for wheat-chickpea rotation and wheat monoculture were 45802.5 and 41860.3 Mj ha^{-1}, respectively. Energy use efficiency for wheat-chickpea rotation and wheat monoculture were 3.4 and 2.8, respectively. In wheat monoculture system, CO_2 emission was about 184.9% higher than wheat-chickpea rotation, which were related to use of fossil fuel (59.2%), nitrogen fertilizer (30.8%), and phosphate fertilizer (7.4%). Nitrogen oxide emissions in wheat monoculture were higher than wheat-chickpea rotation. The global warming potential in wheat monoculture and wheat-chickpea rotation systems were 709.3 and 627.9 kg eq Co_2 h^{-1}, respectively. Overall, the results showed that wheat monoculture has lower energy efficiency and higher global warming potential compared to wheat-chickpea rotation. Therefore, to prevent further emission of greenhouse gases and combat climate change, wheat-chickpea crop rotation is recommended instead of wheat monoculture in dryland agroecosystems.

Highlights

- Wheat-chickpea rotation cuts energy input by 11% (13550.5 vs. 15106.8 MJ ha^{-1}) vs. monoculture.
- Energy efficiency rises 18% in rotation (3.4) over monoculture (2.8) in Kermanshah.
- CO2 emissions 184.9% higher in monoculture due to fossil fuel and nitrogen use.
- Rotation boosts energy output 9% (45802.5 vs. 41860.3 MJ ha^{-1}) vs. monoculture.
- GWP lower in rotation (627.9 kg CO_2 eq ha^{-1}) than monoculture (709.3 kg CO_2 eq ha^{-1}).

1. Introduction

The inappropriate and excessive use of fossil resources by humanity to meet energy needs for ensuring well-being and increasing food supply has led to numerous problems, including the future generations facing fossil fuel shortages, rising energy carrier prices, and climate change phenomena due to greenhouse gas emissions (such as carbon dioxide, methane, and nitrogen oxides). Among the

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most significant outcomes of increased fossil energy consumption are environmental pollution and climate change (Feyzbakhsh and Alizadeh, 2018) **.**

In the essential sectors of human life, agricultural systems act as both energy producers and consumers; thus, a close relationship exists between agriculture and energy consumption (Singh et al., 2004). Today, most developed countries and even developing nations are striving to optimize energy use in agricultural systems by examining energy inputs at various stages of agricultural product production and calculating energy indices (Nasirian et al., 2006). By optimizing the use of energy inputs in agriculture, environmental problems can be minimized, preventing the destruction of Earth's ecological resources and reinforcing sustainable agricultural practices as an appropriate system for agricultural product production (Kizilaslan, 2009). In addition to fossil fuels, the excessive and unprincipled use of chemical inputs such as nitrogen fertilizers in agriculture has caused numerous environmental problems (Soltani et al., 2010), to the extent that this sector contributes nearly 40% of nitrogen oxides emissions (Energy the Balance Sheet, 2008). Another study has reported that nitrogen fertilizer consumption has led to the emission of 10 to 40% of nitrogen oxides (Linzmeier et al., 2001).

As previously mentioned, the increase in agricultural production has resulted in widespread use of agricultural inputs such as chemical fertilizers, pesticides, and agricultural machinery (Brentrup et al., 2004a, 2004b), leading to a severe dependency of the agricultural sector on energy consumption in recent decades (Sefeedpari et al., 2014). High energy consumption has numerous negative effects on the public health of human societies and the environment, emphasizing the importance of examining energy consumption patterns for efficient use in the agricultural sector (Rafiee et al., 2010). Therefore, one of the significant needs for sustainable development in agriculture is studying the effective use of energy and greenhouse gas emissions in agricultural ecosystems (Mohammadi et al., 2011)**.**

Crop rotation is one of the sustainable agricultural strategies that leads to reduced energy consumption in the process of producing agricultural products. Integrating leguminous plants such as chickpea into crop rotation with other crops results in savings in nitrogen fertilizer use (Nemecek et al., 2008), thereby enhancing energy consumption efficiency. In another study, implementing suitable crop rotations was identified as one of the factors reducing fertilizer consumption and consequently lowering energy consumption and greenhouse gas emissions caused by chemical fertilizers, particularly nitrogen, in wheat production in New Zealand (Safa and Samarasinghe, 2012). A study examining the long-term effects of crop rotation and tillage on greenhouse gas emissions in the United States reported that using a corn-soybean rotation led to a reduction in nitrogen oxide emissions by approximately 35% (Behnke et al., 2018). Another research that measured the effects of irrigation, tillage, crop rotation, and nitrogen fertilizer on greenhouse gas emissions in North Dakota indicated that a no tillage chickpea-barley rotation could reduce greenhouse gas emissions (Sainju et al., 2012).

Kermanshah is considered one of the most important provinces for agricultural production in Iran. The province's favorable climatic diversity has led to the cultivation of various agricultural products. The area of Kermanshah's agricultural ecosystems is approximately 840000 ha, of which 74 and 26% are dedicated to dryland and irrigated agroecosystems, respectively (MJA, 2022). One of common crops in the dryland agroecosystems is wheat which usually cultivated either as a monoculture or in rotation with chickpeas. Therefore, wheat and chickpeas are regarded as the most critical agricultural products in Kermanshah province. The objective of this research was 1) to measure energy inputs and energy outputs 2) to calculate the amount of greenhouse gas emissions due to consumption of energy inputs such as nitrogen, phosphorus, potassium, herbicides, insecticides, and fungicides and 3) to evaluate global warming potential in wheat monoculture agroecosystem compared to wheat-chickpea rotation dryland agroecosystem in Kermanshah region.

2. Materials and Methods

This research was conducted in the Kermanshah region (34◦19´N, 47◦50´E, altitude 1400 m) during 2021 (Figure 1). In terms of climate conditions, this region is classified as a semi-arid region based on the Dumartin climate classification (Bagherabadi, 2022), where wheat and chickpeas are cultivated in its dryland agroecosystems, either as a monoculture or in rotation with each other.

Wheat is sown in mid-October to mid-November and it is harvested in early July. Chickpeas are usually sown in mid-March and it is harvested in June. The statistical population included all dryland farmers who cultivated wheat and chickpeas as a monoculture or in rotation with each other. To determine the sample size, Cochran's formula was used (Snedecor and Cochran, 1989):

$$n = \frac{N(s\times t)^2}{(N-1)d^2+(s\times t)^2} \qquad (1)$$

In this equation, s represents the estimate of the population standard deviation, t= 1.96 (at a 95% confidence level), d is the desired precision level set at 0.05, N is the population size (number), and n is the sample size (number). In 2021, approximately 87000 ha of wheat and 36000 ha of chickpeas were cultivated in the dryland agroecosystems of Kermanshah region (MJA, 2022). The number of farmers who cultivated dryland wheat and dryland chickpeas were 17049 and 7790, respectively, and based on the results of Cochran's equation (Eq. 1), 600 farmers (350 and 250 for wheat and chickpeas, respectively) were selected as a sample from the total target statistical population. After determining the number of farmers, information related to all agricultural operations in the wheat and chickpea production process, such as the use of agricultural machinery, preparation of seedbeds, consumption of chemical inputs, fossil fuels, weed control, plant protection , harvesting and transportation of the

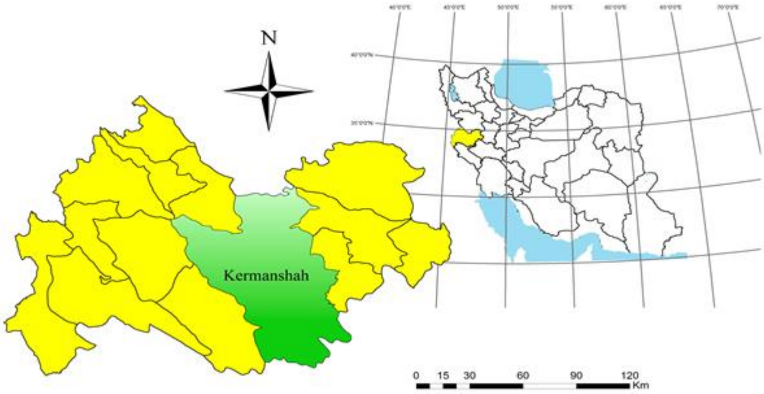

Figure1. Geographical location of the study area (Kermanshah region)

product, was collected in the form of a questionnaire and through face-to-face interviews with farmers and agricultural experts.

2.1. Energy Input (Consumption)

At this stage, the consumption values of each input from planting to harvesting were recorded, and based on the relevant coefficients, the amount of energy input was calculated (Table 1). The total energy input was computed from the sum of energies of labor, machinery, fuel, chemical and animal fertilizers, pesticides, and seeds. To estimate the energy consumption in consumable inputs such as fertilizers, pesticides, and insecticides, the energy per gram of active ingredient was multiplied by the relevant coefficients and their specific weights. Other calculations of consumed energy for inputs and outputs used in production and agricultural operations for each method were carried out using coefficients obtained from various sources.

2.2. Energy Analysis

The data collected through the completion of questionnaires, after classification and processing according to Table 1, was converted into energy equivalents, and all input and output were converted into energy units**.**

Table 1. Equivalents of input and output energies consumed in wheat monoculture and wheat-chickpea rotation ecosystems

Input and output	Unit (hectare)	Energy equivalent	References
		Input	
Human labor	hr	1.96	Ozkan et al., 2004
Seed	kg	14.7	
Machinery	kg	62.7	Hatirili et al., 2005
		Chemical fertilizers	
Nitrogen	kg	66.14	Yilmaz et al., 2005; Esengun et al., 2007
Phosphor	kg	12.44	Yilmaz et al., 2005; Esengun et al., 2007
Potassium	kg	11.15	Yilmaz et al., 2005; Esengun et al., 2007
Diesel fuel	L	51.33	Erdal et al., 2007; Esengun et al., 2007
Herbicides	kg	101.2	Ghiyasi et al., 2008; Yaldiz et al., 1993
Pesticides	kg	199.0	Hensel et al., 1992
Fungicide	kg	181.9	Mohammadi et al., 2008
		Output	
Seed	kg	14.7	Ozkan et al, 2004; Mandal et al.,2002
Straw	kg	12.5	Ozkan et al., 2004; Yousefi et al., 2014

After calculating the energy inputs and energy outputs in the dryland wheat and chickpea agroecosystems, the energy use efficiency (EUE), energy productivity (EP) in kg Mj^{-1}, and net energy (NEY) in Mj ha^{-1} were obtained through equations 2 to 4 (Rezvantalab et al., 2018).

$$EUE=EO/EI \quad (2)$$

$$EP=GY/EI \quad (3)$$

$$NEY=EO-EI \quad (4)$$

In these equations, EO is the total energy outputs (Mj ha^{-1}), EI is the total energy inputs (Mj ha^{-1}), and GY is the grain yield (t ha^{-1}). Subsequently, based on the types of agricultural activities and input resources utilized in the wheat and chickpea dryland agroecosystems, the shares of renewable and non-renewable energies from the total energy consumption were calculated. According to the types of inputs, labor and seed energies were categorized as renewable, while fossil fuels, chemical fertilizers, herbicides, pesticides, fungicides, and machinery categorized as non-renewable energies**.**

2.3. Global Warming Potential (GWP)

The GWP refers to the total amount of greenhouse gases produced, expressed in terms of carbon dioxide equivalents (IPCC, 1996). To calculate the GWP, the emissions of greenhouse gases such as carbon dioxide, nitrous oxide, and methane resulting from energy consumption in the production of inputs and various agricultural operations were considered. These inputs and operations included nitrogen, phosphorus, and potassium fertilizers, chemical herbicides, fungicides, and insecticides, as well as fossil fuel consumption for agricultural operations, transportation, and the production and maintenance of agricultural equipment**.** Finally, to determine the amount of greenhouse gas emissions, the quantities of energy inputs consumed were multiplied by the equivalents of greenhouse gas production and emissions (Table 2) (Rezvantalab et al., 2018)**.**

Table 2. Amounts of greenhouse gas emissions (in grams) per consumption of chemical inputs and global warming potential

Inputs	CH_4	N_2O	CO_2	References
Diesel fuel (L ha^{-1})	5.2	0.7	3560	Kramer et al., 1999
Nitrogen fertilizers (kg ha^{-1})	3.37	0.03	3100	Snyder et al., 2009
Phosphate fertilizers (kg ha^{-1})	1.8	0.02	1000	Snyder et al., 2009
Potassium fertilizers (kg ha^{-1})	1.0	0.1	700	Snyder et al., 2009
Global warming potential	21.0	310.0	1.0	Tzilivakis et al., 2005

2.4. Statistical Analysis

Various input usage values and comprehensive data were collected and recorded at each stage from planting to harvesting, and their processing was performed using Excel software. Data analysis was performed in three sections: energy inputs (consumed), energy outputs (produced), and the GWP resulting from greenhouse gas emissions in the wheat monoculture and wheat-chickpea rotation dryland agroecosystems**.**

3. Results and Discussion

3.1. Input and Output Energies

The total energy input in the wheat monoculture and wheat-chickpea rotation dryland agroecosystems were 15106.8 and 13550.5 Mj ha^{-1}, respectively (Tables 3 and 4). In the wheat monoculture agroecosystem, the highest share of energy consumption corresponded to fossil fuel (37.6%), nitrogen fertilizers (28.9%), and seeds (18.0%). In the wheat-chickpea rotation agroecosystem, the highest share of energy consumption corresponded to fossil fuel (37.1%), nitrogen fertilizers (26.5%), and seeds (19.8%). Although the percentages of consumed energies in the investigated agroecosystems were relatively similar in terms of input contributions, there were differences in the amounts of inputs consumed (Tables 3 and 4).

Table 3. The amount of energy inputs and outputs in the wheat monoculture dryland agroecosystem

Inputs	Unit	Amount	Energy equivalent	Total energy equivalent	Percentage of total
Human labor	hr.ha^{-1}	129.48	1.96	253.78	1.67
Machinery	hr.ha^{-1}	15.83	62.7	992.54	6.57
Diesel fuel	l.ha^{-1}	110.54	51.33	5674.17	37.56
Nitrogen	kg ha^{-1}	66.08	66.14	4370.53	28.93
Phosphor	kg ha^{-1}	49.27	12.44	612.92	4.05
Potassium	kg ha^{-1}	24.22	11.15	270.05	1.78
Herbicides	L ha^{-1}	0.89	101.2	90.07	0.59
Pesticides	L ha^{-1}	0.47	199.0	93.53	0.61
Fungicide	L ha^{-1}	0.27	120.0	32.40	0.21
Seed	kg ha^{-1}	184.82	14.7	2716.85	17.98
Total energy input	MJ ha^{-1}			15106.85	
Wheat grain	kg ha^{-1}	1648.66	14.7	24235.30	57.89
Wheat straw	kg ha^{-1}	1410.00	12.5	17625.00	42.11
Total energy output	MJ ha^{-1}			41860.30	

Table 4. The amount of energy inputs and outputs in the wheat-chickpea rotation dryland agroecosystem

Inputs	Unit	Amount	Energy equivalent	Total energy equivalent	Percentage of total
Human labor	hr.ha^{-1}	112.66	1.96	220.81	1.69
Machinery	hr.ha^{-1}	13.91	62.7	872.16	6.43
Diesel fuel	l.ha^{-1}	97.99	51.33	5029.62	37.11
Nitrogen	kg ha^{-1}	54.22	66.14	3586.11	26.46
Phosphor	kg ha^{-1}	54.07	12.44	672.63	4.96
Potassium	kg ha^{-1}	24.38	11.15	271.84	2
Herbicides	L ha^{-1}	0.78	101.2	78.94	0.58
Pesticides	L ha^{-1}	0.51	199	101.49	0.74
Fungicide	L ha^{-1}	0.26	120	31.2	0.23
Seed	kg ha^{-1}	182.7	14.7	2685.69	19.81
Total energy input	MJ ha^{-1}			13550.48	
Wheat grain	kg ha^{-1}	1870.92	14.7	27502.52	60.04
Wheat straw	kg ha^{-1}	1464	12.5	18300	39.95
Total energy output	MJ ha^{-1}			45802.52	

In the wheat monoculture agroecosystem, the consumption of fossil fuels and nitrogen fertilizers were 110.5 L ha^{-1} and 66.1 kg ha^{-1}, respectively, while these values for the wheat-chickpea rotation agroecosystem were 0.98 L ha^{-1} and 2.54 kg ha^{-1}. The lower input consumption in the wheat-chickpea rotation agroecosystem, compared to wheat monoculture agroecosystem, may be attributed to improved soil nitrogen content and reduced soil compaction. The presence of leguminous plants in the rotation contributes to improving soil nitrogen content through biological nitrogen fixation, while their deep tap root system enhances root development depth, which may impact soil compaction levels**.** Another study has reported that the application of forage crop rotation with legumes in Western Canada resulted in reduced energy consumption compared to monoculture systems (Hoeppner et al., 2000).

The results of this investigation also showed that the total energy output in the dryland wheat monoculture agroecosystem was 41860.3 Mj ha^{-1}, with grain and straw production accounting for 57.9% and 42.1%, respectively (Table 3). The total energy output in the dryland wheat-chickpea rotation agroecosystem was 45802.5 Mj ha^{-1}, with grain and straw production contributing 60.1% and 39.9%, respectively (Table 4).

Table 5. Energy indicators in wheat monoculture and wheat-chickpea rotation dryland agroecosystems

Energy indicators	Unit	Monoculture	Wheat-chickpea rotation
Total energy input	MJ ha^{-1}	15106.8	13550.48
Total energy output	MJ ha^{-1}	41860.3	45802.52
Energy use efficiency	-	2.77	3.38
Energy productivity	kg MJ^{-1}	0.109	0.138
Net energy	MJ ha^{-1}	26753.4	32252.1
Renewable energy	MJ ha^{-1}	2970.6 (19.7%)	2906.5 (21.4%)
Nonrenewable energy	MJ ha^{-1}	12136.2 (80.3%)	10644.0 (78.6%)

3.2. Energy indicators

The total energy input in the wheat monoculture agroecosystem was about 12% higher than in the wheat-chickpea rotation agroecosystem. The total energy output in the wheat monoculture agroecosystem was approximately 9% lower than that of the wheat-chickpea rotation agroecosystem. The energy use efficiency in the dryland wheat-chickpea rotation agroecosystem was about 18% higher than that of the dryland wheat monoculture agroecosystem (Table 5). The lower consumption of chemical inputs and fossil fuels, combined with higher energy outputs, appears to enhance energy use efficiency in the wheat-chickpea rotation agroecosystem compared to wheat monoculture agroecosystem. Another study reported that increasing the diversity of agricultural products and utilizing crop rotation could be an effective method for enhancing energy use efficiency and reducing environmental pollution (Alluvione et al., 2011). Other researchers, by examining the effects of crop rotation on the energy efficiency of irrigated potato with cereals, canola, and alfalfa over a 14-year period in Canada, emphasized that potato producers should incorporate legumes into their crop rotation systems to maintain yield levels while increasing energy use efficiency (Khakbazan et al., 2019)**.**

For every unit of energy in the wheat-chickpea dryland agroecosystem, 0.13 kg of grain are produced, whereas under monoculture conditions, 0.10 kg of grain are produced. The energy productivity in the wheat-chickpea rotation agroecosystem is approximately 21% higher than that of the wheat monoculture agroecosystem. The lower energy consumption and more optimal use of energy inputs during their conversion to dry matter in the wheat-chickpea rotation compared to monoculture conditions may have led to the improvement in energy productivity. Additionally, in the wheat-chickpea dryland agroecosystem, the net energy is 17% higher than in the wheat monoculture agroecosystem. In the wheat-chickpea rotation agroecosystem, the shares of non-renewable and renewable energies are 78.6% and 21.4%, respectively, while in the wheat monoculture agroecosystem, the shares of these energies are 80.3% and 19.7% of total energy input (Table 5). Renewable energies have an ecological origin that is produced within the agroecosystems, whereas non-renewable energies are imported from outside the agroecosystems. Therefore, the higher the proportion of renewable energies in the management of agricultural systems, the greater the sustainability of those agroecosystems. In another study, it was reported that the proper application of crop rotation resulted in improved energy productivity (Khakbazan et al., 2019). It has also been reported that the use of crop rotation involving forage crops with legumes led to a reduction in the consumption of non-renewable energies due to the biological nitrogen fixation by legumes (Hoeppner et al., 2000).

3.3. Global Warming Potential (GWP)

The GWP in the wheat monoculture and wheat-chickpea rotation agroecosystems were 709.28 and 672.92 kg eq CO_2 h^{-1}, respectively (Table 6). The GWP in wheat monoculture agroecosystem was 11.50% higher compared to the wheat-chickpea rotation agroecosystem. In the wheat monoculture and wheat-chickpea rotation agroecosystems, fossil fuel consumption had the largest share in the emissions of greenhouse gases CO_2, N_2O, and CH_4. The highest and lowest greenhouse gas emissions were attributed to fossil fuel consumption and potassium fertilizers, respectively (Table 6). Results also indicated that nitrogen fertilizer consumption in the wheat monoculture agroecosystem was higher than in the wheat-chickpea rotation agroecosystem.

It seems that in the wheat monoculture agroecosystems, due to the plant's inadequate response to the consumed nitrogen, increasing nitrogen levels may not significantly improve yield and, therefore, nitrogen uptake efficiency is low under. In another study, it was determined that transitioning from traditional rotation (celery-tomato-lettuce) to modified (clover-tomato-lettuce) reduced nitrogen fertilizer input by up to 25%, nitrous oxide emissions by up to 24%, and the GWP by up to 14% (Min et al., 2016). The presence of legume crops in crop rotation in Mediterranean dryland agroecosystems significantly altered greenhouse gas emissions and carbon sequestration due to low soil organic matter content and fertility (Guardia et al., 2016). Another study reported that lupin-wheat rotation, compared to wheat monoculture, resulted in reduced greenhouse gas emissions (Barton et al., 2013).

Table 6. Greenhouse gases emission (kg ha^{-1}) and global warming potential (kg eq Co$_2$ h^{-1}) in wheat monoculture and wheat-chickpea rotation agroecosystems

Inputs	Monoculture				Wheat-chickpea rotation			
	CO_2	N_2O	CH_4	GWP	CO_2	N_2O	CH_4	GWP
Diesel fuel	393.53	0.0773	0.5748	429.56	348.83	0.0685	0.5095	380.76
Nitrogen fertilizers	204.84	0.0019	0.2226	210.10	168.08	0.0016	0.1827	172.41
Phosphate fertilizers	49.27	0.0009	0.0886	51.41	54.07	0.0010	0.0973	56.42
Potassium fertilizers	16.954	0.0024	0.0242	18.21	17.066	0.0024	0.0243	18.32
Global warming potential				709.28				627.92

The results of this study also indicated that the application of nitrogen fertilizers led to higher greenhouse gas emissions and GWP compared to other chemical inputs (Table 6). The nitrogen emission coefficient (1.3 kg CO_2 kg^{-1}$_N$) is higher compared to phosphorus and potassium (Lal, 2004), which is related to the nitrogen fixation and production process in the factory (Snyder et al., 2009). The production of nitrogen in the factory is a very costly process that directly uses fossil fuels as an energy source. Therefore, any approach that can lead to a reduction in the consumption of synthetic nitrogen in agroecosystems could directly decrease greenhouse gas emissions and GWP during the agricultural product production process. Increasing biodiversity through crop rotation is one of the most important factors in enhancing nitrogen efficiency in agroecosystems (Montemuro et al., 2006). In rotational systems, the productivity of consumed resources, especially accessible nitrogen, increases due to improved plant growth conditions and reduced limiting factors for production, while nitrogen losses are minimized. Choosing a high-efficiency nitrogen rotation system reduces the dependence of agroecosystems on nitrogen fertilizers and thus decreases energy consumption and enhances system sustainability. Since the amount of fertilizer applied per production yield in rotational systems is less than in monoculture agroecosystems, the land use efficiency in a rotational pattern will increase at intermediate and low nitrogen levels (Franszluebbers et al., 1995).

4. Conclusion

To achieve a suitable level of sustainability in agroecosystems, it is essential to consider the balance between energy inputs and energy outputs, as increased energy inputs reduces energy efficiency. The results of this study showed that in the wheat-chickpea rotation agroecosystem compared to the wheat monoculture agroecosystem the total energy input was lower, while in this agroecosystem the total energy output was higher. The energy use efficiency and the energy productivity were higher in the wheat-chickpea rotation agroecosystem compared to the wheat monoculture agroecosystem. The greenhouse gas emissions in the wheat-chickpea rotation agroecosystem compared to wheat monoculture agroecosystem was lower due to reduced consumption of fossil fuels and nitrogen fertilizers. Planting chickpeas before wheat had positive effects, such as soil fertility improvement, reduced need for nitrogen fertilizer, decreased use of agricultural equipment, and ultimately increased wheat grain yield. These results led to lower greenhouse gas emissions and, consequently, a reduced GWP. Therefore, to prevent greenhouse gas emissions in Kermanshah's dryland agroecosystems, it is recommended to further promote the wheat-chickpea crop rotation agroecosystem compared to wheat monoculture agroecosystem.

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