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Energy budget and economic analysis of modern and traditional wheat production systems in Kurdistan province of Iran

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Abstract
This study was conducted to analyze input-output energies and economic analysis of modern and traditional wheat production systems of Kurdistan province, Iran. Data were collected from 100 dryland and 100 irrigated wheat fields. The fields were selected randomly, and inquiries conducted in a face-to-face interview from May up to August next year. The results showed that total energy inputs, energy use efficiency, and specific energy were 49,956 MJ ha^{-1}, 2.4, and 4.9 MJ kg^{-1} in modern irrigated wheat system, respectively, 19,064 MJ ha^{-1}, 3.4, and 3.4 MJ kg^{-1} in traditional irrigated wheat system, 16,598 MJ ha^{-1}, 1.7, and 6.7 MJ kg^{-1} in modern dryland wheat system, and 14,471 MJ ha^{-1}, 1.99 and 5.75 MJ kg^{-1} in traditional dryland wheat system, respectively. The economic analysis revealed that the total cost of production and net return were 546.5 and 1,448.6 USD ha^{-1} in modern irrigated wheat, 206.4 and 844.7 USD ha^{-1} in traditional irrigated wheat, 230.5 and 237.6 USD ha^{-1} in modern dryland wheat and 185.2 and 266.1 USD ha^{-1} in traditional dryland wheat systems, respectively. The results of this study showed that the modern wheat production system uses more energy compared to that by the traditional wheat production system. Thus, the wheat producers are advised to adopt modern wheat production systems with some caution.

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Introduction

Within the past 30 years, commercial farming has overcome subsistence farming as the dominant mode of agricultural production in Iran (Saheb et al., 2023). More than 22% of the total population of Iran is engaged in the agricultural sector, while the share of agriculture was 5 to 16 percent of gross domestic production (GDP) during past decades (Karandish et al., 2021).

The productivity and profitability of wheat production systems depend on energy consumption, especially nonrenewable energy. Modern wheat production systems, as well as other crops, are characterized by the high input of fossil energy. This energy is directly consumed as fuel and electricity, and indirectly in manufacturing fertilizers, plant protection products, machines, etc.; while traditional wheat production systems mostly rely on renewable energy such as animals, human labor, farmyard manure, etc. Advances in agricultural technologies have caused an increase in wheat yield and farmers'

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income in modern systems, without paying attention to ecological consequences. Although this is unavoidable on one side, because of the population pressure and increasing demand for food, on the other side, this leads to the introduction of agrochemicals, increasing pressure on natural resources, increment in the use of nonrenewable energy, resource pollution, increased CO_2 concentration, climate change, and other negative effects. Based on a comprehensive study in China, it has been shown that energy use efficiency estimated at 1.98 in 1991 and 1.38 in 2012, caused an average annual decrease of 1.69% (Yuan and Peng, 2017). This shows that if the increase in production of agricultural ecosystems takes place without considering the energy aspects, it will leave disastrous consequences in the future.

Since the Iranian agricultural sector enjoys high subsidies on fossil fuels and electricity from the government, the rate of energy consumption in this section is high. Therefore, during past decades, with the global rise in energy prices, the Iranian government has taken some steps to reduce fuel and energy consumption in all sectors of the economy (Tabar et al., 2010; Ghadaksaz and Saboohi, 2020). The implication of such policies in Iran has raised awareness of the use of energy. Thus, studying the energy use pattern to identify energy-intensive areas of agricultural production systems and assess the energy use efficiency, environmental problems, and their relations with sustainability seem essential (Pourmehdi and Kheiralipour, 2024). To achieve this goal, it is necessary to analyze the cropping systems in terms of energy and to evaluate alternative solutions, especially for wheat, which covers more than 6 million hectares of Iran's cultivable lands (Salarpour et al., 2020).

The energy analysis of agricultural systems is well documented in the literature (Tsatsarelis, 1991; Esengun et al., 2007; Erdal et al., 2007; Mohammadi et al., 2008; Mobtaker et al., 2010; Salimi and Ahmadi, 2010; Yuan and Peng, 2017; Du et al., 2023; Pourmehdi and Kheiralipour, 2024). Comparative studies were also performed between modern and traditional or organic systems by many researchers (Hoeppner et al., 2005; Gundogmus, 2006; Kaltsas et al., 2007; Kumar et al., 2023), but there are very limited reports about this branch of research in Iran. Therefore, the aim of this study was to compare modern and traditional wheat production systems in Kurdistan province, concerning input-output energy analysis, economic analysis, energy use, and energy use efficiency.

Material and Methods

This study was carried out in 100 dryland and 100 irrigated wheat farms in Kurdistan, located in the west of Iran within 34° 35′ and 36° 28′ north latitude and 45° 34′ and 48° 14′ east longitude. Data was collected from the growers by filling out a face-to-face questionnaire.

Fields were randomly selected from the villages in the study area. The quantity of inputs was calculated per ha and then multiplied with the coefficient of energy equivalents (**Table 1**). The mechanical energy was computed based on the total fuel consumption (L ha^{-1}) in different operations. Therefore, the consumed energy was calculated using the conversion factor (1 L diesel = 56.31 MJ) and expressed in MJ ha^{-1} (Tsatsarelis, 1991). To calculate the energy equivalent of ox in traditional system, the feed needed per one hour of ox work should be estimated, which is equal to 0.75 kg of concentrated maize and 1.5 kg of hay (Pimentel et al., 1999). Thereupon the energy value of consumed maize concentrate and hay was calculated using appropriate energy equivalents as an energy input for ox.

Based on the energy equivalents of the inputs and outputs (**Table 1**), the energy ratio (energy use efficiency), energy productivity, specific energy, and net energy were calculated using the following equations (Ghorbani et al., 2011):

Energy use efficiency = energy output (MJ ha^{-1})/energy input (MJ ha^{-1}) (1)
Energy productivity = wheat yield (kg ha^{-1})/energy input (MJ ha^{-1}) (2)
Specific energy = energy input (MJ ha^{-1})/ wheat yield (kg ha^{-1}) (3)
Net energy = energy output (MJ ha^{-1}) - energy input (MJ ha^{-1}) (4)

Indirect energy includes the energy embodied in seeds, fertilizers, manure, chemicals, machinery, etc. while direct energy covers human labor, diesel, and ox used in the wheat production. Economic analysis of wheat production was calculated based on equations 5-7.

Gross production = [grain yield (kg ha^{-1}) × grain price ($ kg^{-1})] + [straw yield (kg ha^{-1}) × straw price ($ kg^{-1})] (5)
Net return = gross production value ($ ha^{-1}) – total cost of production ($ ha^{-1}) (6)
Benefit to cost ratio = gross value of production ($ ha^{-1})/ total cost of production ($ ha^{-1}) (7)

Table 1. Energy equivalent of inputs and outputs in agricultural production

Particulars	Unit	Energy equivalent (MJ unit^{-1})	Reference
Input			
Human labor	H	1.96	(Ghorbani et al., 2011)
Machinery	H	62.7	(Ghorbani et al., 2011)
Diesel fuel	L	56.31	(Ghorbani et al., 2011)
Chemical fertilizers	kg		
Nitrogen (N)		66.14	(Ghorbani et al., 2011)
Phosphate (P_2O_5)		12.44	(Ghorbani et al., 2011)
Farmyard manure	kg	0.30	(Ghorbani et al., 2011)
Concentrate	kg	14.64	(Ghorbani et al., 2011)
Hay	kg	12.55	(Ghorbani et al., 2011)
Chemicals	kg		
Herbicide		238.00	(Ghorbani et al., 2011)
Fungicide		92.00	(Ghorbani et al., 2011)
Pesticide		199.00	(Ghorbani et al., 2011)
Micro-nutrition		120.00	(Ghorbani et al., 2011)
Irrigation water	m^3	1.02	(Ghorbani et al., 2011)
Seeds	kg	20.1	(Ghorbani et al., 2011)
Output			
Wheat grain	kg	14.48	(Ghorbani et al., 2011)
Wheat straw	kg	9.25	(Singh et al., 1998)

Results

Management practices in traditional fields

Traditional fields had operated by landowners until two decades ago, when they were gradually replaced by modern agriculture. The average sizes of those fields were 0.83 and 4.53 ha for irrigated and dryland wheat, respectively. More than 95% of the wheat-cultivated area was under dryland wheat. Irrigated wheat was arranged in rotation with other crops like potato, alfalfa, onion, and vegetables, while dryland production systems were performed in the wheat-fallow system. **Table 2** shows the relevant agronomic practices during the growing period of wheat in the study area.

Fundamental bases of irrigated and dryland wheat are the same with only a little difference. Since irrigated wheat was cultivated in rotation with other crops, therefore, land preparation was done after the harvest of summer crops, and the animal was used just for a reduced tillage with drown chisel plow. The maximum and average yields of traditional irrigated wheat fields were 4.1 and 2.53 tons/ha, respectively.

In an overall view, traditional system of wheat production is a sustainable system without any use of agrochemicals, which was carried out totally by labor, and animal. Therefore, it prevented the squander of nonrenewable energy and bioenvironmental negative effects of agrochemicals.

Management practices in modern fields

The average sizes of modern fields were 8.23 and 21.32 ha for irrigated and dryland systems, respectively. More than 90% of wheat-cultivated area belonged to dryland wheat. There were significant differences between modern and traditional systems. In fact, mechanization and agrochemicals application caused a fundamental change in the agricultural principles of the region. On one side, farmers' welfare raised because of the increasing income, however, on the other side, irregular consumption of agrochemicals and nonrenewable energy such as fossil fuel had caused new problems, thereby triggering increased ecological consequences. More details about practices and operations of modern wheat production are shown in **Table 2**.

Input-output energy use in modern and traditional irrigated wheat production

Table 3 shows the rates of inputs and output energies of irrigated wheat and their equivalents. The total energy used in modern production of irrigated wheat was 49,956 MJ ha^{-1}. Agrochemicals constituted 47.44% (23,699 MJ ha^{-1}) of the total energy inputs in modern system, which is alone higher than the total energy inputs in the traditional system. Among the agrochemicals, nitrogen is the highest energy consumer (41.8% of total energy inputs). After agrochemicals, the share of diesel fuel plus machinery is 26.8% of the total energy inputs, followed by that of irrigation water (13.0%) and seed (12.0%). The role of human labor in modern production of irrigated wheat was little, because it consumed only 0.7% of the total energy inputs.

Table 2. Management practices for wheat production in Kurdistan Province, Iran

	Irrigated wheat		Dryland wheat	
Practices/operations	Modern	Traditional	Modern	Traditional
Average farm size (ha)	8.23	0.83	21.32	4.53
Land preparation tools	Tractor: 285 MF 75 hp	Ox and labor	Tractor: 285 MF 75 hp	Ox and labor
Land preparation practices	Moldboard plow, Disc harrows	Animal drown chisel plow	Moldboard plow, Disc harrows	Animal drown plow; Animal drown leveler
Land preparation period	Varied from beginning of September to late October	Zero till based (varied from beginning of September to late October)	In fallow year (varied from middle of May to late August)	In fallow year (varied from beginning of May to late August)
Planting instrument	Deep furrow drill	Handmade	Deep furrow drill	Handmade
Planting period	Varied from beginning of October to late November	During October	Varied from mid of September to mid of October	Varied from mid of September to mid of October
Fertilization type	Mostly chemical	Farmyard manure	Mostly chemical	Mostly Fallow-based
Fertilization period	Before planting (basal fertilizers); after active growth at spring (from beginning of April to beginning of June)	Before planting	Before planting (basal fertilizers); after active growth in Spring (from beginning of April to mid of May)	-
Weeding	Chemically	-	-	-
Weeding period	From beginning of April to beginning of May	-	-	-
Pest and disease control	Chemically	-	Chemically	-
Pest and disease control period	Before planting (seed fumigation); Start of April to mid-June (to control fungi & pests)	-	Before planting (seed fumigation); Mid May to mid June (control pests)	-
Irrigations	Sprinkler	Flooding	-	-
Average number of irrigations	8.2	4.3	-	-
Harvesting	Combine	Reaping	Combine	Reaping
Harvesting period	During July	From beginning of July to early August	During July	From beginning of July to mid of August

Since agrochemicals and diesel fuel were not used in the traditional production of wheat, therefore, the total energy inputs were very low, compared with the modern system (19,064.0 MJ ha^{-1}; **Table 3**). Most of this energy was related to ox, which consumed 455.2 kg hay (i.e. 5,713.1 MJ energy), and 227.6 kg concentrate (i.e. 3,332.2 MJ energy) per 303.5 hour work during the growing season. The consumed energy by the irrigation water (5,255.4 MJ ha^{-1}), seed (3,020.2 MJ ha^{-1}), human labor (1,039.2 MJ ha^{-1}) and farmyard manure (703.7 MJ ha^{-1}) were 27.57%, 15.84%, 5.45%, and 3.69 % of the total energy inputs, respectively. The average annual yield and the total energy output of traditional irrigated fields were 2,536.4 kg ha^{-1} and 65,006.0 MJ ha^{-1}, respectively.

Table 4 shows the energy use efficiency, specific energy, energy productivity, and net energy of the irrigated wheat production in the Kurdistan province. Energy use efficiency (energy ratio) was 2.40 and 3.41 in the modern and traditional systems, respectively. Reduced tillage in the traditional irrigated wheat had an important role in raising energy use efficiency. The average energy productivity of modern and traditional fields of irrigated wheat had been 0.2 and 0.29, respectively. This means that 20% and 29% of a unit of input energy had been fixed in outputs in modern and traditional systems, respectively.

The percentage of direct energy, indirect energy, renewable and non-renewable energy of modern irrigated wheat had been 34.73, 65.27, 12.70 and 87.30, respectively, and the percentage of the above-mentioned items in the traditional production had been 80.47, 19.53, 72.43, and 27.57 (**Table 5**). An important point of these results is that the share of renewable energy decreased from 72.43% in the traditional to 12.7% in the modern system.

Table 3. Inputs and outputs in irrigated wheat production of Kurdistan Province, Iran

	Quantity per unit area (ha)		Total energy equivalent (MJ ha^{-1})		Percentage of the total energy (%)	
	Modern farms	**Traditional farms**	**Modern farms**	**Traditional farms**	**Modern farms**	**Traditional farms**
Input						
Human labor (h)	176.12	530.19	345.20	1039.17	0.69	5.45
Ox (h)	-	303.49	-	-	-	-
Concentrate (kg)	-	227.61	-	3332.21	-	17.48
Hay (kg)	-	455.23	-	5713.14	-	29.97
Machinery (h)	46.43	-	2911.16	-	5.83	-
Diesel fuel (L)	186.27	-	10488.86	-	21	-
Chemicals (kg)	481.41	-		-		-
nitrogen (N)	315.63	-	20875.77	-	41.79	-
phosphate (P_2O_5)	106.34	-	1994.63	-	3.99	-
herbicide	1.23	-	292.74	-	0.59	-
fungicide	1.62	-	149.04	-	0.30	-
pesticide	0.95	-	189.05	-	0.38	-
micro-nutrition	1.64	-	196.80	-	0.39	-
Farmyard manure (kg)	-	2345.68	-	703.70	-	3.69
Irrigation water (m^3)	6386.66	5152.32	6514.39	5255.37	13.04	27.57
Seed (kg)	298.43	150.26	5998.44	3020.23	12.01	15.84
Total energy input (MJ)			49956.08	19063.82		
Outputs						
Wheat grain yield (kg)	4936.26	2536.41	71477.04	36727.22	59.63	56.50
Wheat straw yield (kg)	5231.48	3057.16	48391.19	28278.73	40.37	43.50
Total energy output (MJ)			119868.23	65005.95		

Table 4. Energy input-output relations in wheat production of Kurdistan Province, Iran

		Irrigated wheat		Dryland wheat	
Items	Unit	Modern farms	Traditional farms	Modern farms	Traditional farms
Energy input	MJ ha^{-1}	49956.1	19063.8	16598.3	14471.2
Energy output	MJ ha^{-1}	119868.2	65006.0	28769.2	28804.5
Grain Yield	kg ha^{-1}	4936.3	2536.4	1136.3	1058.4
Straw yield	kg ha^{-1}	5231.5	3057.2	1331.5	1457.2
Energy use efficiency	-	2.4	3.4	1.7	2.0
Specific energy	MJ kg^{-1}	4.9	3.4	6.7	5.8
Energy productivity	kg MJ^{-1}	0.2	0.3	0.2	0.2
Net energy	MJ ha^{-1}	69912.2	45942.1	12170.9	14333.3

Table 5. Total energy input in the form of direct, indirect, renewable, and non-renewable for irrigated wheat production (MJ ha^{-1}) in Kurdistan Province, Iran

Form of energy (MJ ha^{-1})	Modern farms	Percentage of total energy input	Traditional farms	Percentage of total energy input
Direct energy ^{a}	17348.5	34.7	15339.9	80.5
Indirect energy ^{b}	32607.6	65.3	3723.9	19.5
Renewable energy ^{c}	6343.6	12.7	13808.5	72.4
Non-renewable energy ^{d}	43612.5	87.3	5255.4	27.6
Total energy input	49956.1		19063.8	

a Includes human labor, diesel, irrigation, ox (concentrate & hay)
b Includes seed, fertilizers, farmyard manure, chemicals, machinery
c Includes human labor, seed, farmyard manure, ox (concentrate & hay)
d Includes diesel, chemical, fertilizers, machinery, irrigation water

Input-output energy use in modern and traditional dryland wheat production

Table 6 shows the amount of input and output energy rates of the dryland wheat and its equivalents. The total energy used in the modern production of dryland wheat was 16,598.31 MJ ha^{-1}, which is 67% lower than that of the irrigated wheat. Unlike the irrigated wheat, diesel fuel plus machinery was the highest energy consumer (56.4% of total energy inputs) followed by agrochemicals (30.0%), seed (12.5%) and human labor (1.2%). Like in the irrigated wheat, nitrogen was the highest energy consumer among the agrochemicals (89.4 % of the total energy used by agrochemicals and 26.8% of total energy inputs).

The results for the traditional dryland wheat production are very interesting. Surprisingly, the total energy inputs of the traditional system were renewable energy. In fact, the production of wheat relied merely on two sources: human labor and ox (**Table 6**). The total energy input was 14,471 MJ ha^{-1} and the energy consumed by the ox work was 86.4% of the total energy inputs (12,542 MJ ha^{-1}). The share of seed and human labor were 7.9% and 5.4% of the total energy inputs, respectively. Since there had been machinery absence and time limitation for preparing lands by animal, the fallow duration sometimes extended by two and/or more years. Therefore, the fertility of the lands was maintained at a high value, and the wheat yield was very close to that was obtained through the modern system, in which mean annual yield, and total energy outputs had been 1,058.41 kg ha^{-1} and 28,804.51 MJ ha^{-1}, respectively.

As it is shown in **Table 4**, the amounts of traditional energy use efficiency, energy productivity and net energy were higher than those of the modern system. The calculated energy ratios were 1.73 and 1.99 for the modern and traditional systems of dryland wheat, respectively. Of course, while comparing with the irrigated wheat system, the rate of energy use efficiency decreased in both systems, which was mostly due to high yield of irrigated rather than that of dryland wheat.

As mentioned earlier, the share of renewable energy in the traditional dryland wheat production was 100%, 92.06% of which related to direct energy, while the amount of renewable energy in the modern system had been 13.66% (**Table 7**). Although mechanization and agrochemicals caused an increment in wheat-cultivated area, crop yield and farmers' income during the past two decades, it had led to a decrease in the sustainability of wheat production. The efficient utilization of energy in agriculture may lessen some negative impacts on the environment, reduce demands on natural resources, and increase sustainability within food production (Khan et al., 2009). Since all the energy inputs in the traditional dryland wheat production of Kurdistan province were renewable energy sources, so the energy use efficiency of that system was higher than that of the modern one. Thus, it can be concluded that traditional production was a sustainable system.

Table 6. Inputs and outputs in dryland wheat production of Kurdistan Province, Iran

	Quantity per unit area (ha)		Total energy equivalent (MJ ha^{-1})		Percentage of the total energy input (%)	
	Modern farms	Traditional farms	Modern farms	Traditional farms	Modern farms	Traditional farms
Input						
Human labor (h)	101.56	398.17	199.06	780.41	1.20	5.39
Ox (h)	-	420.82	-	-	-	-
Concentrate (kg)	-	315.61	-	4620.53	-	31.93
Hay (kg)	-	631.23	-	7921.94	-	54.47
Machinery (h)	30.49	-	1911.72	-	11.52	-
Diesel fuel (L)	132.21	-	7444.75	-	44.85	-
Chemicals (kg)	98.97	-	-	-	-	-
nitrogen (N)	67.22	-	4445.93	-	26.79	-
phosphate (P_2O_5)	30.84	-	383.65	-	2.31	-
herbicide	-	-	-	-	-	-
fungicide	0.34	-	31.28	-	0.19	-
pesticide	0.57	-	113.43	-	0.68	-
Seeds (kg)	102.91	57.13	2068.49	1148.31	12.46	7.94
Total energy input (MJ)			16598.31	14471.19		
Outputs						
Wheat grain yield (kg)	1136.26	1058.41	16453.04	15325.78	57.18	53.21
Wheat straw yield (kg)	1331.48	1457.16	12316.19	13478.73	42.81	46.79
Total energy output (MJ)			28769.23	28804.51		

Table 7. Total energy input in the form of direct, indirect, renewable, and non-renewable forms for dryland wheat production (MJ ha^{-1}) in Kurdistan Province, Iran

Form of energy (MJ ha^{-1})	Modern farms	Percentage of total energy input	Traditional farms	Percentage of total energy input
Direct energy [a]	7643.8	46.1	13322.9	92.1
Indirect energy [b]	8954.5	54.0	1148.3	7.9
Renewable energy [c]	2267.6	13.7	14471.2	100.0
Non-renewable energy [d]	14330.8	86.3	0.0	0.0
Total energy input	16598.3		14471.2	

a Includes human labor, diesel, irrigation, ox (concentrate & hay)
b Includes seed, fertilizers, farmyard manure, chemicals, machinery
c Includes human labor, seed, farmyard manure, ox (concentrate & hay)
d Includes diesel, chemical, fertilizers, machinery, irrigation water

Economic analysis of wheat production systems

The total cost of the produced wheat and the gross value of production were calculated and shown in **Table 8**. In order to appraise the comparison between the traditional and the modern systems, the economic value of expenditure and output of the traditional system was calculated based on current equivalent prices. The total expenditure and the gross value of production per hectare of modern irrigated wheat had been 546.54 and 1995.17 USD, respectively, and in the traditional irrigated wheat the amounts of the variables mentioned were estimated as 206.35 and 1051.02 USD ha^{-1}. The net return values of the modern and traditional irrigated wheat systems were 1,448.63 and 844.67 USD ha^{-1}, respectively. The total expenditure, the gross value of production and the net return per hectare of the modern dryland wheat were 230.54, 468.17 and 237.63 USD, respectively, and the estimated amounts of the variables mentioned in the traditional dryland wheat were 185.23, 451.28 and 266.05 USD. Although the net return of the traditional dryland wheat system was higher than that of modern, the total income of modern farmers was higher, because machinery caused an increment in wheat cultivated area, in which the average sizes of the traditional and modern dryland wheat systems were 4.53 and 21.32 ha, respectively.

Table 8. Economic analysis of wheat grain and straw in Kurdistan Province, Iran

Cost and return components	Value $			
	Irrigated wheat		Dryland wheat	
	Modern farms	Traditional farms	Modern farms	Traditional farms
Grain yield (kg ha^{-1})	4936.3	2536.4	1136.3	1058.4
Grain sale price (USD kg^{-1})	0.33	0.33	0.33	0.33
Straw yield (kg ha^{-1})	5231.5	3057.2	1331.5	1457.2
Straw sale price (USD kg^{-1})	0.07	0.07	0.07	0.07
Gross value of production (USD ha^{-1})	1995.2	1051.02	468.17	451.28
Total cost of production (USD ha^{-1})	546.5	206.4	230.5	185.2
Net return (USD ha^{-1})	1448.6	844.7	237.6	266.1
Benefit to cost ratio	3.65	5.09	2.03	2.44

Discussion

The results presented here show that by changing traditional wheat production to modern system, the net return increases, and this may lead to the change of production strategy from sustainable to more economic production. The consequence of these alterations is the reliance of agriculture on nonrenewable energy resources. Ghorbani et al. (2011) reported that the shares of agrochemicals, diesel fuel plus machinery, irrigation water, seed, and human labor were 38.8%, 26.6%, 13.5%, 11.1% and 0.46% of the total energy inputs, respectively, which are very close to our results. Average annual yield of the modern fields was 4,936 kg ha^{-1} and the total energy output 119,868 MJ ha^{-1}. They also evaluated that the total energy input and output in irrigated wheat production being 45,367 and 65,336 MJ ha^{-1}, respectively. The energy inputs in the Iranian agricultural productions were reported by researchers, as for potato (81,625 MJ ha^{-1}) (Mohammadi et al., 2008), greenhouse cucumber (148,837 MJ ha^{-1}) (Mohammadi and Omid, 2010), barley (25,027 MJ ha^{-1}) (Mobtaker et al., 2010), kiwifruit (30,286 MJ ha^{-1}) (Mohammadi et al., 2010) and irrigated wheat (20,813 MJ ha^{-1}) (Pourmehdi and Kheiralipour, 2024). The variation among energy inputs of these crops is mostly due to the amount of nitrogen application and diesel fuel consumption. Most of this energy was consumed in the application of nitrogen, phosphorus, and potassium fertilizers. For example, the amount of nitrogen application in barley production was 84 kg ha^{-1} (Mobtaker et al., 2010), while in our study, it was 315.6 kg ha^{-1}. In a recent study in Iran, nitrogen fertilizer used in irrigated wheat fields was estimated to be 64.24 kg ha^{-1} (Pourmehdi and Kheiralipour, 2024), which was about 20% of the nitrogen used in our study. Therefore, the difference in the consumption of inputs may cause a significant difference in the energy consumption of the whole system. According to Singh et al. (1998), the energy used in the production of fertilizer may account for about 40% of the total energy used in agricultural production in the developed countries.

Energy use efficiency of the irrigated wheat production in the Kurdistan province was 2.40 and 3.41 in the modern and the traditional systems, respectively. Reduced tillage in the traditional irrigated wheat had an important role in raising energy use efficiency. The results of many studies showed that energy use efficiency of the systems which rely on natural resources and renewable energy, is higher than that of a system that relies on agrochemicals and machinery (Gundogmus, 2006; Kaltsas et al., 2007). A study conducted in China shows that average energy return on investment values of wheat, maize, and rice production was estimated to be 0.94, 1.1, and 1.3, respectively (Yan et al., 2023). The energy ratio varied from site to site and it was mostly dependent on crop yield, agronomical practices of production system, and the region of production. For example, the reported energy ratio for winter wheat varied from 1.44 (Ghorbani et al., 2011) to 6.36 (Pourmehdi and Kheiralipour, 2024) in Iran.

The calculation of crop energy productivity rate is well documented in the literature such as wheat (0.06) (Ghorbani et al., 2011), barley (0.19) (Mobtaker et al., 2010), stake-tomato (1.0) (Esengun et al., 2007), and sugar beet (1.53) (Erdal et al., 2007). The specific energy and net energy of the irrigated wheat production system were 4.91 MJ kg $^{-1}$ and 69,912.15 MJ ha^{-1} for modern and 3.40 MJ kg $^{-1}$ and 45,942.13 MJ ha^{-1} for the traditional system. Canakci et al. (2005) reported specific energy of field crops and vegetable production in Turkey as 5.24 for wheat, 11.24 for cotton, 3.88 for maize, 16.21 for sesame, 1.14 for tomato, 0.98 for melon and 0.97 for watermelon.

The sustainability of traditional wheat production system is higher than that of modern systems, because the production of wheat in the past mostly relied on renewable energy in which the share of renewable energy were 72.43% and 100 % of total energy inputs in irrigated and dryland wheat production, respectively, while the percentage of renewable energy in modern system falls to 12.70% and 13.66 % for the irrigated and dryland wheat production systems, respectively. Since the availability of nonrenewable energy sources such as fossil fuel and agrochemicals and their prices are variable, therefore, the modern wheat production is more sensitive to fluctuation of availability and prices, compared to the traditional system.

In the recent decades, modern agriculture is one of the main aspects of urbanization, especially in developing countries like Iran, and this may increase unemployment rate further. This is a very important challenge, and it seems that we do not have any solution except a sustainable utilization of resources. For this, we should apply traditional principles of agriculture in a combination with modern agriculture. This is a very important fact from an ecological point of view, since the sources of nonrenewable energy such as fossil fuel are terminable, and also, they are pollutants.

The results of a long-term study indicated that the Iranian agriculture is heavily dependent on non-renewable energy sources (about 87%) (Tabar et al., 2010). High consumption of nonrenewable energy causes a decrement in energy use efficiency, because the production of agrochemicals and machinery used are the main constituents of modern agriculture, and they require a lot of energy.

Ghorbani et al. (2011) also showed that total energy input and output in dryland wheat production were 9,354 and 31,672 MJ ha^{-1}, respectively. In another study conducted in Kurdistan province (Salimi and Ahmadi, 2010), the rate of energy inputs in dryland production was reported for chickpea as 5,880 MJ ha^{-1}. The difference between total energy inputs of our results and dryland chickpea production of Kurdistan province (Salimi and Ahmadi, 2010) may have been due to the amount of nitrogen application (22.26 kg ha^{-1} vs. 67.22 kg ha^{-1}) and diesel fuel consumption (39.61 L ha^{-1} vs. 132.21 L ha^{-1}).

There are very limited studies related to the comparison between traditional and modern wheat production systems, but there are several studies, which compare the energy analysis of organic with modern production systems (Hoeppner et al., 2005; Kaltsas et al., 2007; Georgieva et al., 2022; Gao et al., 2023).

Although the use of fossil fuel energy and agrochemicals is inevitable to provide enough food for the current world population, in order to increase the sustainability of current production systems, we should adopt traditional or organic systems. For example, producing chemical fertilizers, especially nitrogen, which is one of the most important factors in modern crop production, demands a high quantity of energy and this energy in most cases is nonrenewable. In contrary, farmyard manure is renewable and demands low energy for production. Therefore, the application of natural fertilizers instead of chemical types helps increase renewable energy in agricultural production systems. For realizing this aim, a change in production strategy from one-function to multiple-function system is needed.

Conclusion

In this study, the energy inputs and outputs for modern and traditional wheat production were examined in the Kurdistan Province of Iran. During the past two decades, the change in wheat production from traditional to modern system caused an increment in crop yield and farmers' income. The yield increase was mostly due to further application of inputs, especially agrochemicals and machinery, but not due to the increase in resource use efficiency, since the energy use efficiency of both irrigated and dryland wheat was higher in traditional than that in modern system. Therefore, the application of renewable inputs should be considered instead of chemical types to increase sustainability of wheat production systems.

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Contribution of authors
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This study does not involve human/animal subjects, and thus no ethical approval is needed.

Handling of bio-hazardous materials
The authors certify that all experimental materials were handled with care during collection and experimental procedures. After completion of the experiment, all materials were properly discarded to minimize/eliminate any types of bio-contamination(s).

Availability of primary data and materials
As per editorial policy, experimental materials, primary data, or software codes are not submitted to the publisher. These are available with the corresponding author and/or with other author(s) as declared by the corresponding author of this manuscript.

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It is declared that we the authors did not use any AI tools or AI-assisted services in the preparation, analysis, or creation of this manuscript submitted for publication in the International Journal of Applied and Experimental Biology (IJAaEB).

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