ORIGINAL ARTICLE

Evaluation of energy indices and greenhouse gas emissions in major horticultural crops and paddy crops in Tajan plain

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Abstract

One of the basic objectives of sustainable agriculture is the efficient use of available inputs and resources. Hence, energy use was evaluated in the present study for the cultivation and the greenhouse gas emissions in the main horticultural crops and paddy in Tajan. The required data were collected through relying on subjective and objective methods such as questionnaries and field data recorded in Tajan plain in the period of 2020–2022. The maximum input energy was reported 64,867.5 MJ/ha for the cultivation of rice, and the minimum amount of input energy belonging to pear cultivation was 30,982.95 MJ/ha. Similarly, the highest amount of output energy was recorded 86,401 MJ/ha for the cultivation of rice crops, and the lowest amount of output energy was 30,400 MJ/ha in the cultivation of pomegranate. The results taken from the GHG index and the global warming potential indicated that the products including paddy (2726.19 kg CO_2/ha), apple (2681.6 kg CO_2/ha) and citrus (2545.3 kg CO_2/ha) had the highest impact on pollution and greenhouse gas emissions. Subsequently, according to the data regarding the cultivation percentage of each crop, it was found out that paddy crop had the largest share of potential impact on global warming (72,789,535.76 kg CO2) in Tajan plain. Therefore, the production of products with incredibly high water consumption as well as great use of chemical fertilizers and old high-working hour machines have greater share in energy consumption and global heating potential in comparison to the other indices.

Introduction

Water is the main factor in the survival of all living beings, and it is obvious that it plays essential in agriculture, domestic use, industrial entrance, tourism and culture and the preservation of land ecosystems, environment, economics and development in every country and is important in terms of food security growth (Odhiambo 2016). One of the most important issues in this field is the management of energy consumption in agriculture and the emission of greenhouse gasses which are created as a side-effect of agricultural activities. The energy balance has become crucial in recent years due to the global crisis over the possibility of fossil fuels diminishing; thus, the amount of energy consumed and estimated in different sectors had to be recognized and managed (Platis et al. 2019). According to a global analysis, about 5% of the total energy consumption belongs to the agricultural sector. In the same way, 11% of all greenhouse gas emissions belong to agricultural activities (Smith et al. 2014). Most of this pollution is the result of fossil fuel consumption, electricity consumption, fertilizers, pesticides, and agricultural and tillage operations (Camargo et al. 2013). One of the applied methods to reduce energy consumption and production costs and mitigate GHG pollution is to lower their impact in the agricultural sector, since it can lessen the impacts of global warming universally and preserve resources for the community. Hence, evaluation of energy consumption in this sector is a requirement to determine energy efficiency. Developing countries are now the cause of three-quarters of direct greenhouse gas (GHG) emissions, and it is expected for them to become the fastest-growing sources and producers of greenhouse gas emissions in future

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(Pachauri et al. 2014). CO2 and CH4 have played the most significant role in greenhouse gas emissions in the majority of studies (Yapıcıoğlu and Demir 2021; IPCC 2014; Kumar et al. 2021).

Water, food, and energy are interconnected components which entail integrated management and cannot be examined separately. There is an interconnected cycle in water, food and energy where water is used as the main input in different sectors, including food production (El-Gafy 2017).

In a study conducted by Vahedi and Zarif Neshat (2021) on irrigated wheat in Alborz, Isfahan, Ardabil, Khorasan Razavi, Khuzestan, Golestan and Hamedan provinces, the reported average input energy, output energy, energy efficiency, specific energy and net energy in the studied provinces were 5830.83 MJ/ha, 136,092.15 MJ/ha, 2.87 kg/M, 0.212 kg/M and 77,783.31 MJ/ha, respectively.

Similarly, in a study on the wheat product in Gorgan, Soltani et al. (2014) it was revealed that the input energy associated with fuel operations had the highest level among other input energies with an average of 3390 MJ/ha and nitrogen fertilizer with 5964 MJ/ha. Another research on evaluation of energy indicators and the potential for global warming systems of rice production systems conducted in Sari proved that the total input energy in the paddy was 55,332 MJ/ha and the total output energy was reported 80,377 MJ/ha (Ansari et al. 2015). The amount of nitrogen share in wheat energy was reported 38.03% in the other studies (Toroudi et al. 2018).

Vafabakhsh and mohammadzadeh (2019), too, studied the energy flow and emissions of greenhouse gasses in crop and garden production systems in Sharifabad plain and discovered that the highest energy consumption belonged to the production of alfalfa, pomegranate and grapes with 94,906 MJ/ha, 79,696 MJ/ha and 78,984 MJ/ha, respectively, and so did the highest output energy to alfalfa products, forage and wheat products with 218,567 MJ/ha, 171,810 MJ/ha and 123,430 MJ/ha. They similarly reported that the highest energy consumption was for barley products (2.9), forage corn (2.8) and wheat (2.6) and so was the lowest energy consumption for pistachios (0.34), pomegranate (0.48) and cotton (0.9). Energy indices in peach production were investigated by Royan et al. (2011) and the results showed that the total energy input in the production of this product and output energy levels were 37,531.49 MJ/ha and 20,894.2 MJ/ha, respectively. The values related to consumption efficiency, the total net energy consumption and energy efficiency were 0.55, 16,636.56 MJ/ha and 0.29 kg/MJ too.

In a study carried out by Aghkhani et al. (2018) on energy consumption and greenhouse gas emissions in citrus production, it was discovered that the two inputs of animal fertilizer and fuel with 48.5% and 16.9% enjoyed the highest energy-draining inputs in the energy sector; moreover, these two inputs had the highest impact in the greenhouse gas emissions with 43.3% and 18.5%, respectively. In another study investigating the energy and greenhouse gas emissions in Guilan province, 75% of greenhouse gas emissions was caused by gasoline (44%) and nitrogen as fertilizer (31%) (Salar Ashayeri et al. 2020).

Various studies were conducted by some researchers (e.g., Tzilivakis et al. 2005; Khoshnevisan et al. 2013; Yousefi et al. 2016; Mohammadi et al. 2014; Vafabakhsh and Mohammadzadeh 2019) in the field of greenhouse gas emissions from agricultural and horticultural crops. They found out that the amount of energy and greenhouse gas index is different according to the type of agricultural operation. Most of these studies considered the variables of electricity required by the water pump engines, nitrogen fertilizer and gasoline, the main origins of greenhouse gas emissions. In most of the recent research, either the energy indicators or fewer agricultural and garden products have been investigated; while in the present study, the paddy products were first investigated which have a special place in the world in terms of consumption, and the citrus orchards the products whereof are highly consumed in the world were then examined. Furthermore, the main innovation of the present study is to investigate the emission of greenhouse gasses in a large area, (i.e., the amount of greenhouse gasses emission per hectare was first checked, and it was then extended to the whole plain).

Few studies have so far been carried out on energy indices and greenhouse gas emissions in garden and agricultural products in Mazandaran province. It implies the necessity of understanding and addressing these issues in this region. Hence, energy indices and greenhouse gas emissions were studied regarding major garden and paddy products in Tajan plain.

Materials and Methods

The study location is in Sari, Mazandaran. The reported average annual rainfall in this city is 615 mm. The field-work of the present paper was carried out in Shahid Rajaee Dam in Sari. The irrigation and drainage system of Tajan plain covers an area of 56,000 hectares of agricultural land, accounting for nearly 43,000 hectares of crops and 13,000 hectares of fruit gardens. Figure 1 shows the geographical location of the study area.

The field data in the period of 2020–2021 regarding major garden products from the lands of Shahid Rajaee dam in Tajan plain including citrus, peach, pomegranate, apple and pears and paddy were used to calculate the amount of energy production and the greenhouse gasses. The collected data consisted of the consummation amount of each input, the amount of production, and the cost and production values. Inputs used in the cultivation of the above-mentioned
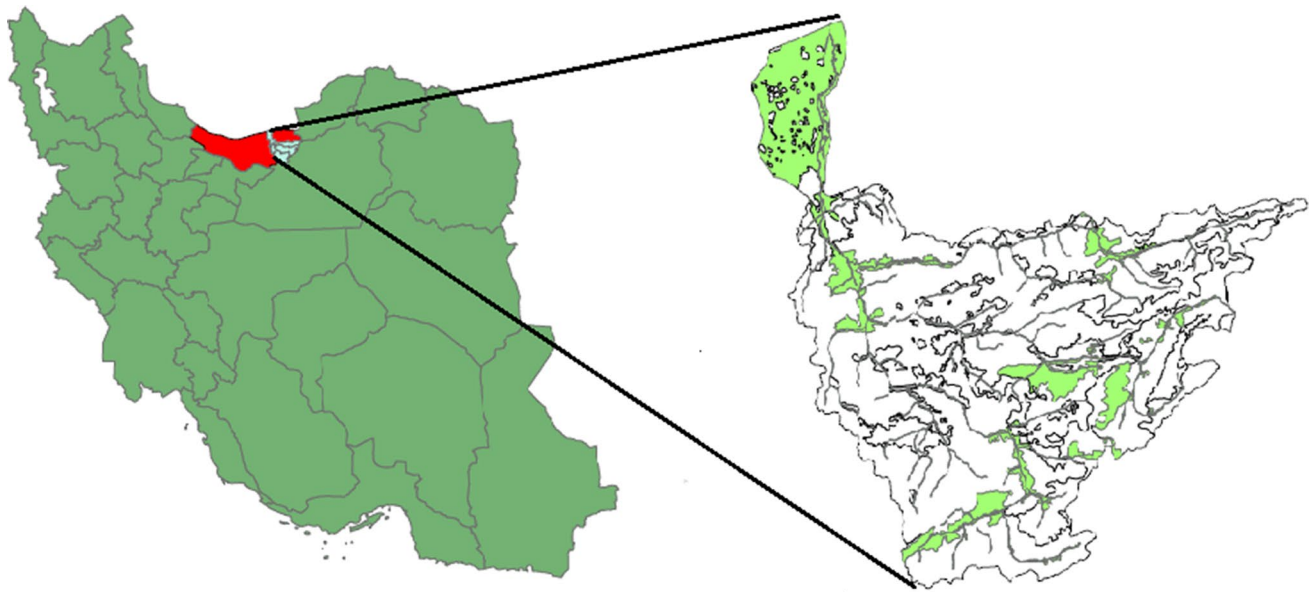
Fig. 1 Study area of Tajan plain in Sari County, Mazandaran Province, Iran

products in Tajan plain include manpower, the amount of fuel consumption in liters, machinery hours, nitrogen fertilizers, phosphate, potassium in kg/ha, the amount of consumption of chemical poisons involving herbicides, fungicides, mineral oil and insecticide in l/ha, the amount of water consumed in terms of cubic meters per hectare. SPSS software was used to find the outlier data, and so was EXCEL software to analyze the data and do calculations related to energy indicators and greenhouse gas emissions. The required data were collected during one cropping season. The data and information were regularly collected during eight months from the beginning of the cropping season through referring to the lands and gardens under study. It is worth mentioning that the researcher was present at all stages including fertilizing, spraying, watering, planting seeds, working hours of manpower and agricultural machinery.

Calculation of energy indices

Equivalent energy recommendations about each input and output factor were used to estimate energy indices (Table 1). To compare energy indices, all input and output data in the cultivation and production were reported as averages.

The following equations were used to calculate energy indices (Pimentel 1980; Herrhz et al. 1995; Hatirli et al. 2006):

Table 1 Equivalent to input and output energy in the production of studied products in the Tajan plain

	Unit	Energy equivalents (MJ. unit-1)	Reference
(a) Inputs			
Human labor	hr	1.96	De et al. (2001)
Machinery	hr	62.7	Mandal et al. (2002)
Diesel	l	47.8	Kitani (1999)
Nitrogen	kg	66.14	Hatirli et al. (2006)
Phosphorus(P_2O_5)	kg	12.44	Hatirli et al. (2006)
Potassium (K_2O)	kg	11.15	Hatirli et al. (2006)
Herbicides	l	85	Kitani (1999)
Insecticides	l	229	Kitani (1999)
Fungicides	l	216	(Mohammadi et al.,2010)
Mineral oil	l	43.2	(Mohammadi et al.,2010)
Irrigation water	M^3	1.02	Acaroglu (1998)
Paddy Seed	kg	14.57	(Mansoori et al. 2012)
(b) Outputs	–	–	–
Citrus	kg	1.9	(Singh et al.,1992)
Peach	kg	1.9	(Singh et al.,1992)
Pomegranate	kg	1.9	(Singh et al.,1992)
Apple	kg	1.9	(Singh et al.,1992)
pear	kg	1.9	(Singh et al.,1992)
Paddy	kg	14.57	(Mansoori et al. 2012)
Straw	kg	12.5	(Mansoori et al. 2012)

$$\text{Energy use efficiency} = \frac{\text{Output energy}\left(\frac{\text{MJ}}{\text{ha}}\right)}{\text{Input energy}\left(\frac{\text{MJ}}{\text{ha}}\right)} \qquad (1)$$

$$\text{Energy productivity} = \frac{\text{Yield}\left(\frac{\text{kg}}{\text{ha}}\right)}{\text{Input energy}\left(\frac{\text{MJ}}{\text{ha}}\right)} \qquad (2)$$

$$\text{Specific energy} = \frac{\text{Input energy}\left(\frac{\text{MJ}}{\text{ha}}\right)}{\text{Yield}\left(\frac{\text{kg}}{\text{ha}}\right)} \qquad (3)$$

$$\text{Net energy} = \text{Output energy}\left(\frac{\text{MJ}}{\text{ha}}\right) - \text{Input energy(MJ/ha}) \qquad (4)$$

Calculation of greenhouse gas emissions

The greenhouse gas emissions of each of the chemical inputs were calculated according to CO2, N2O and CH4 emission coefficients presented in Table 2. Also, the global warming potential per hectare was calculated based on the emission rate of each of the greenhouse gasses and their impact coefficient for 100 years, which was equal to 1, 30 and 21 for CO2, N2O and CH4, respectively (IPCC 1995). Finally, the global warming potential of the greenhouse gas emissions of the major crops per hectare was calculated in Tajan Plain based on the CO2 equivalent.

Results and Discussion

Energy indices

Input, output and equivalent energy values in the cultivation of horticultural products in Tajan plain are presented in Tables 3 and 4. In comparison to the horticultural products studied in the input energy sector, citrus needs 840 h per

Table 2 Gaseous emissions (g) per unit of input

Factor	CH_4	N_2O	CO_2	Reference
Diesel(L)	5.20	0.7	3560	Kramer et al. (1999)
Nitrogen(kg)	3.7	0.03	3100	Snyder et al. (2009)
Phosphorus(kg)	1.8	0.02	1000	Snyder et al. (2009)
Potassium (kg)	1	0.01	700	Snyder et al. (2009)
Herbicide (kg)	–	–	6300	Lal (2004)
Insecticide (kg)	–	–	5100	Lal (2004)
CO_2 equivalence factor	21	30	1	IPCC (1995)

Table 3 Input and output values of inputs in the production of studied products in Tajan plain

	Unit	Citrus(ha^{-1})	Peach (ha^{-1})	Pomegranate (ha^{-1})	Apple (ha^{-1})	pear (ha^{-1})	Paddy (ha^{-1})
Inputs							
Human labor	hr	840	770	800	780	750	380
Machinery	hr	62	85	60	56	55	340
Diesel	l	170	175	165	155	150	220
Nitrogen	kg	175	155	95	200	55	200
Phosphorus(P$_2$O$_5$)	kg	150	100	75	175	50	160
Potassium (K$_2$O)	kg	140	100	70	150	60	70
Herbicides	l	15	18	15	19	14	5
Insecticides	l	9	10	6	5	7	7
Fungicides	l	13	9	7	9	10	7
Mineral oil	l	60	15	–	–	–	–
Seed	kg	–	–	–	–	–	70
Irrigation water	M^3	5000	11,000	16,000	10,000	9000	11,500
Outputs							
Citrus	kg	22,500	–	–	–	–	–
Peach	kg	–	20,000	–	–	–	–
Pomegranate	kg	–	–	16,000	–	–	–
Apple	kg	–	–	–	17,500	–	–
pear	kg	–	–	–	–	13,500	–
Paddy	kg	–	–	–	–	–	4300
Straw	kg	–	–	–	–	–	1900

Table 4 Input and output energy in the production of studied products in Tajan plain

Inputs	Unit	Citrus	Percent of total	Peach	Percent of total	Pomegranate	Percent of total	Apple	Percent of total	pear	Percent of total	Paddy	Percent of total
Human labor	MJ/ha	1646.4	3.89	1509.2	3.47	1568	3.76	1528.8	3.44	1470	4.74	744.8	1.1
Machinery	MJ/ha	3887.4	9.18	5329.5	12.26	3762	9.02	3511.2	7.9	3448.5	11.13	21,318	31.4
Diesel	MJ/ha	8126	19.19	8365	19.25	7887	18.91	7409	16.7	7170	23.14	10,516	15.49
Nitrogen	MJ/ha	11,574.5	27.34	8267.5	19.02	6283.3	15.07	13,228	29.8	3637.7	11.74	13,228	19.48
Phosphorus(P_2O_5)	MJ/ha	1866	4.4	1244	2.86	933	2.24	2177	4.9	622	2	1990.4	2.93
Potassium (K_2O)	MJ/ha	1393.75	3.3	1115	2.56	780.5	1.87	1672.5	3.8	501.75	1.62	780.5	1.15
Herbicides	MJ/ha	1275	3	1530	3.52	1275	3.06	1615	3.63	1190	3.84	425	0.63
Insecticides	MJ/ha	2061	6.63	1603	4.47	1374	3.63	2290	4.37	1145	6.97	1603	2.22
Fungicides	MJ/ha	2808	4.37	1994	5.27	1512	3.3	1944	2.58	2160	5.17	1512	2.36
Mineral oil	MJ/ha	2592	2.57	648	1.5	–	–	–	–	–	–	3024	4.45
Seed	MJ/ha	–	–	–	–	–	–	–	–	–	–	1019.9	1.5
Irrigation water	MJ/ha	5100	12	11,220	25.81	16,320	39.14	10,200	22.95	9180	29.63	11,730	17.27
Outputs	MJ/ha	42,750	–	38,000	–	30,400	–	33,250	–	25,650	–	86,401	–

hectare (1646.4 MJ/ha) (i.e., more manpower than the other products). Similarly, pomegranate requires 800 h per hectare (1568 MJ/ha), and the products with the lowest amount of required manpower are apple with 780 an hour per hectare (1528.8 MJ/ha), peach with 770 h per hectare (1509.2 MJ/ha), pear with 750 h per hectare (1470 MJ/ha) and paddy with 380 h per hectare (744.8 MJ/ha).

The lowest working hours per hectare for pear production was 55.

After examining the results related to human power, the results of agricultural machinery working hours were examined in different garden and paddy crops, and the findings showed that the machinery working hours per hectare was 55 from the beginning of the cropping season to its end for pear production (the lowest working hours per hectare) and the highest working hours per hectare belonged to the paddy crop with 340 (21,318 MJ/ha). Moreover, the lowest working hours per hectare was 55 for pear production (3448.5 MJ/ha). Ansari et al. (2015) evaluated the energy indicators and global warming potential of rice production systems in a study conducted in Sari; the machines working hours were reported to be 350 (21,945 MJ/ha). In a study conducted by Royan et al. (2011) in Golestan province on crop energy indices, it was found out that the amount of energy used by machinery in peach production was 3790.54 MJ/ha. In the same way, Agkhani et al. (2015) have estimated citrus cultivation energy indices in Mazandaran province and found that the amount of energy used by machines in the production was 5256.55 MJ/ha.

Due to the fact that the machines used in the studied area are 100% diesel and these machines have a long life, they have a high consumption (50 to 250 L per hectare from the beginning of the cropping season to its end). As a result, diesel consumption is one of the most important sources of energy production needed for machines and water pump motors to pump water in the studied area. Among the studied products, the lowest consumption of diesel belongs to the production of pear in 150 L per hectare (7170 MJ/ha) and the highest consumption of diesel belongs to the production of rice with 220 L per hectare (10,516 MJ/ha). In a study conducted by Ansari et al. (2015), the amount of input energy in the production of paddy was 7600 MJ/ha. Royan et al. (2011), too, reported 9877.9 MJ/ha as the amount of energy input for fuel in the production of the peach product. Likewise, in a study by Aghkhani et al. (2018), the amount of fuel input in citrus production was reported 18,782.68 MJ/ha. The reason for this non-uniformity in the amount of input energy regarding diesel fuel consumption can be taken as the difference in equivalent coefficients.

The findings showed that the chemical toxins have the lowest share of total input energy among the studied energy inputs. Beheshti Tabar et al. (2010) reported in their research

that the share of pesticides in the total input energy in crop production was less than other inputs.

The results of this research show that three parameters including irrigation (24.61%), nitrogen fertilizer (20.55%) and fuel (18.9%) have the largest share of total input energy. The comparison between the studied crops in Tajan plain shows that the share of irrigation from the total input energy is the highest in the pomegranate crop with 39.1% and the lowest in citrus crop with 12%. Furthermore, the highest amount of nitrogen and fuel consumption is recorded in crops including apple (29.7%) and pear (23.14%) and the lowest amounts of nitrogen and fuel consumption belong to pear (11.7%) and paddy (16.2%), respectively. In a similar study, researchers (Royan et al. 2011; Aghkhani et al. 2018; Ansari et al. 2015) revealed that the share of nitrogen, irrigation water and fuel from input energy is 14%, 3% and 26% for peach crop, 19.24%, 1.81% and 16.91% for citrus crop and 20.8%, 12.5% and 13.7% for rice paddy, respectively. Figure 2 shows the average energy inputs per parameter in the production of horticultural products in the Tajan plain.

Energy indices for horticultural and paddy crops in Tajan plain have been calculated, and the results are given in Table 5. The results show that paddy, apple, peach and citrus have the highest input amounts (64,867.5, 44,430.5,

43,462.2 and 42,330.05 MJ/ha); pomegranate and pear have the lowest amount of input energy with 41,694.8 and 30,982.95 MJ/ha, respectively. The results of the output energy index show that its highest amount is seen among the products related to paddy (86,401 MJ / ha), citrus (42,750 MJ / ha) and peach (38,000 MJ / ha) and the lowest amount was among pears (25,650 MJ / ha), pomegranates (30,400 MJ / ha) and apples (32,250 MJ / ha).

In a similar study, the output energy for citrus crops was reported 77,824.2 MJ/ha (Aghkhani et al. 2018), 13,276.5 MJ/ha for pomegranate crops (Trojani et al. 2017), 20,894.92 MJ/ha for peach crops (Royan et al. 2011) 52,993.76 MJ/ha and for nectarine (Khojastehpour et al. 2015). The reason for the increase in the output energy in the products under study can be associated with farmers' willingness to use modern irrigation, up-to-date machinery, and modification of management practices that increase yield and the output energy.

The results of net energy depict that in this section, paddy (21,533.4 MJ / ha) and citrus (419.95 MJ / ha) have the highest amount of net energy and apple products (-11,180.5 MJ / ha), pomegranate (−11,294.8 MJ / ha), peach (−5462.2 MJ/ha) and pear (−5232.95 MJ/ha) enjoy the lowest amount of net energy. In the other research,

Fig. 2 Average energy inputs per parameter in the production of horticultural products in the Tajan plain (percentage)
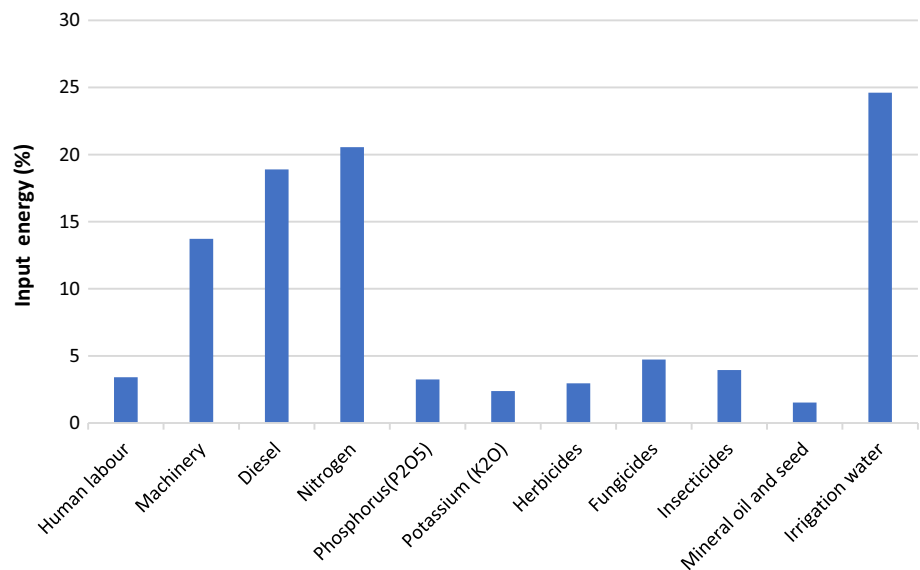
Table 5 Energy indicators in the production of studied products in the Tajan plain

Energy indicators	Unit	Citrus	Peach	Pomegranate	Apple	pear	paddy
Input energy	MJ/ha	42,330.05	43,462.2	41,694.8	44,430.5	30,982.95	67,891.6
Output energy	MJ/ha	42,750	38,000	30,400	32,250	25,650	86,401
Net energy	MJ/ha	419.95	−5462.2	−11,294.8	−11,180.5	−5332.95	18,509.4
Energy use efficiency	–	1	0.87	0.73	0.75	0.83	1.27
Specific energy	MJ.kg^{-1}	1.88	2.17	2.6	2.54	2.3	10.95
Energy productivity	Kg.MJ^{-1}	0.53	0.46	0.38	0.39	0.46	0.091

the amount of net energy was reported 24,945 MJ/ha for paddy (Ansari et al. 2015),−16,636.56 MJ/ha for peach (Royan et al. 2011), -27,484.42 MJ/ha for citrus crop (Aghkhani et al. 2018), and −41,296 MJ/ha for pomegranate (Vafabakhsh and Mohammadzadeh 2019).

The findings show that regarding energy efficiency, paddy, citrus and peach have the highest consumption level with 1.33, 1 and 0.87, respectively; and pear, apple and pomegranate have lower efficiencies with 0.83, 0.75 and 0.73, respectively, when compared to citrus and peach. The results of the present study were consistent with that of the study by Ansari et al. (2015), who calculated 1.45 the energy efficiency.

The investigation on the specific energy index in the studied products showed that rice (10.46 MJ / kg) and pomegranate (2.6 MJ / kg) have the highest amount of specific energy and citrus (1.88 MJ / kg) has the lowest. Also, the study of the energy efficiency index showed that citrus (0.56 MJ / kg) has the highest energy efficiency level and paddy (0.1 MJ / kg) has the lowest level.

Global warming potential

The current emission of greenhouse gasses is presented in Fig. 3 for horticultural crops in Tajan Plain. These results show the amount of greenhouse gas emissions and conclude that the global warming potential is 2726.19 kg CO_2 per hectare in paddy crops, 2681.6 kg CO_2 per hectare in apple products and 2545.3 kg CO_2 per hectare in citrus. These products have the highest share of impact in comparison to peach crops with 2202.3 kg CO_2 per hectare, pomegranate with 1886.7 kg CO_2 per hectare and pears with 1535.3 kg CO_2 per hectare.

In a study by Dastan et al. (2012), the global warming potential for paddy production was reported to be 2307 kg/ha CO_2. In another study conducted by Mohammadi et al.

(2014), the potential of global warming of wheat in the northern Iran was found to be 1171.1 kg CO_2 per hectare. Similarly, in a study by Aghkhani et al. (2018), the amount of greenhouse gas emissions from citrus production in Mazandaran was reported to be 2876.22 kg CO_2 per hectare.

Table 6 is drafted to explain the impact of each effective factor on greenhouse gas emissions more profoundly. The data indicate that in most of the researched crops, diesel fuel and nitrogen fertilizer had the greatest share of impact on the overall greenhouse gas emission, such that the share of these two inputs is 82%, 75%, 73%, 73%, 72% and 70% in rice, pomegranate, peach, pear, citrus and apple products, respectively. Furthermore, the cultivation area for different crops is calculated to properly determine the amount of greenhouse gas emissions based on different cultivation areas of the crops. The results showed that the highest total greenhouse gas emissions (about 70%) belong to the paddy crop and the second to citrus (almost 20%). The rest of the crops had lower percentages due to smaller cultivation areas.

Conclusion

According to the results, the highest input energy belonged to paddy, apple, peach and citrus crops and so did the lowest amount to pomegranate and pear crops. In addition, in the output energy section, the highest energy belonged to paddy, citrus and peach products and so did the lowest to apple, pomegranate and pear products. Considering that area under study has a moderate and humid climate; therefore, products such as apple did not show high efficiency due to insufficient cooling requirements, and this very fact can influence the net energy and cause this parameter to become negative. Also, due to the high level of worn-out machinery use and high fuel consumption, and the application of chemical fertilizers and pesticides rather than organic materials in some

Fig. 3 Greenhouse gas emission rates of horticultural crops and paddy crop in Tajan plain
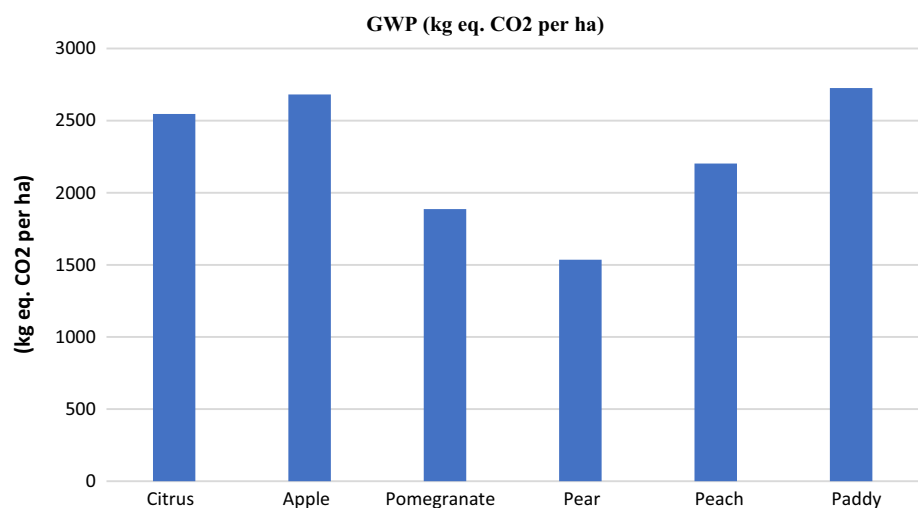
Table 6 Parameters affecting the emission of greenhouse gasses and the total emission of greenhouse gasses based on the cultivation area

Factor	Unit	Citrus (%)		Apple (%)		Pomegranate (%)		Pear (%)		Peach (%)		Paddy (%)	
Diesel(L)	lit	962.23	37.79	877.32	32.72	933.93	49.50	849.02	55.30	990.53	44.98	1245.23	45.68
Nitrogen(Kg)	kg	862.15	33.86	985.31	36.74	468.02	24.81	270.96	17.65	615.82	27.96	985.31	36.14
Phosphorus(Kg)	kg	238.53	9.37	278.28	10.38	119.26	6.32	79.51	5.18	159.02	7.22	254.43	9.33
Potassium (Kg)	kg	139.09	5.46	166.91	6.22	77.89	4.13	50.07	3.26	111.27	5.05	77.89	2.86
Herbicide (Kg)	lit	150.00	5.89	220.00	8.20	150.00	7.95	140.00	9.12	180.00	8.17	50.00	1.83
Insecticide (Kg)	lit	194.29	7.63	153.81	5.74	137.62	7.29	145.71	9.49	145.71	6.62	113.33	4.16
Gwp Co2 Equivalence Factor	(kg eq. CO2 per ha)	2546.28	100	2681.64	100	1886.72	100	1535.28	100	2202.35	100	2726.20	100.00
Total Area Under Cultivation	ha	8150.00	20.53	950.00	2.40	1700.00	4.28	500.00	1.26	1700.00	4.28	26,700.00	67.25
Total GWP	kg eq. CO2	20,752,163.89	19.99	2,547,553.93	3.50	3,207,427.91	4.41	767,640.16	1.05	3,743,998.37	5.14	72,789,535.76	70.12

products such as apple, pomegranate, peach, and pear, the output energy is much lower than the input energy. It was found out that it made the net energy negative. It is worth mentioning that the paddy product has energy efficiency above 1 because of having two outputs (paddy + straw) in the output part. Furthermore, in regard to global warming potential, paddy, apple and citrus crops had the largest share of impact among the crops, which was determined according to the percentage of cultivation for each crop. The crop with the highest global warming potential in Tajan plain was paddy product with 72,789,535.76 kg CO_2 emission. The comparison made on the impact of different inputs on the total global warming potential of crops showed that in most of the studied crops, diesel fuel and nitrogen fertilizer had the biggest influence on greenhouse gas emissions. Therefore, the cultivation of products which use high amounts of water, while requiring a lot of chemical fertilizers and being worked on by old machines with high working hours has a greater share in the amount of consuming energy and global warming potential in comparison to the other products. Therefore, proper management and optimization of irrigation systems to increase water use efficiency, deploying modern and up-to-date machinery with lower fuel consumption, applying organic and animal fertilizers, and adopting appropriate farming operations instead of chemical fertilizers can increase energy efficiency and reduce greenhouse gas emissions.

Declarations

References

Acaroglu M (1998) Energy from biomass, and applications. University of Selcuk, Graduate school of natural and applied sciences, Turkey, p 43

Aghkhani MH, Ahmadipour S, Soltanali H, Rohani A (2018) Greenhouse gas emission, energy use and cost analysis of citrus

production: case study of Mazandaran province. J Energy Plan Policy Res 4(3):181–229

Ansari MJ, Khoramdel S, Ghorbani R, Pirdashti H (2015) Evaluation of global warming potential for rice in the first and second cropping patterns (Case study: Sari Province). Res Field Crop J 3(1):14–26

Beheshti Tabar I, Keyhani A, Rafiee S (2010) Energy balance in Iran's agronomy (1990–2006). Renew Sustain Energy Rev 14:849–855

Camargo GG, Ryan MR, Richard TL (2013) Energy use and greenhouse gas emissions from crop production using the farm energy analysis tool. Bioscience 63:263–273

De D, Singh R, Chandra H (2001) Technological impact on energy consumption in rainfed soybean cultivation in Madhya Pradesh. Appl Energy 70:193–213

El-Gafy I (2017) Water–food–energy nexus index: analysis of water–energy–food nexus of crop's production system applying the indicators approach. Appl Water Sci 7(6):2857–2868

Hatirli SA, Ozkan B, Fert C (2006) Energy inputs and crop yield relationship in greenhouse tomato production. Renewable Energy 31:427–438

Herrhz JL, Girth VS, Cerisola C (1995) Long-term energy use and economic evaluation of three tillage systems for cereal and legume production in central Spain. Soil and Tillage Res 35:183–198

IPCC 2014 (2014) Climate change 2014: mitigation of climate change. summary for policymakers and technical summary

IPCC (1995) Climate Change, the Science of Climate Change. In: Houghton JT, Meira Filho LG, Callander BA, Harris N, Kattenberg A, Maskell K (Eds) Intergovernmental panel on climate change. Cambridge: Cambridge University Press.

Khojastehpour M, Nikkhah A, Hashemabadi D (2015) A comparative study of energy use and greenhouse gas emissions of canola Production. Inter J Agric Manage Develop 5(1):51–58

Khoshnevisan B, Rafiee S, Omid M, Yousefi M, Movahedi M (2013) Modeling of energy consumption and GHG (greenhouse gas) emissions in wheat production in Esfahan province of Iran using artificial neural networks. Energy 52:333–338

Kitani O (1999) CIGR Handbook of Agricultural Engineering. American Society of Agricultural Engineers, United States of America

Kramer KJ, Moll HC, Nonhebel S (1999) Total greenhouse gas emissions related to the Dutch crop production system. Agr Ecosyst Environ 72:9–16

Kumar A, Thanki A, Padhiyar H, Singh NK, Pandey S, Yadav M, Yu ZG (2021) Greenhouse gases emission control in WWTS via potential operational strategies: a critical review. Chemosphere.

Lal R (2004) Carbon emission from farm operations. Environ Int 30:981–990

Mandal K, Saha K, Ghosh P, Hati K, Bandyopadhyay K (2002) Bioenergy and economic analysis of soybean-based crop production systems in central India. Biomass Bioenerg 23:337–345

Mansoori H, Rezvani Moghaddam P, Moradi R (2012) Energy budget and economic analysis in conventional and organic rice production systems and organic scenarios in the transition period in Iran. Frontiers in Energy 6(4):341–350

Mohammadi A, Rafiee S, Jafari A, Keyhani A, Mousavi-Avval SH, Nonhebel S (2014) Energy use efficiency and greenhouse gas emissions of farming systems in north Iran. Renew Sustain Energy Rev 30:724–733

Odhiambo GO (2017) Water scarcity in the Arabian Peninsula and socio-economic implications. Appl Water Sci 7(5):2479–2492

Pachauri RK, Allen MR, Barros VR, Broome J, Cramer W, Christ R, van Ypserle JP (2014) Climate change 2014: synthesis report.

Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change (p. 151). Ipcc.

Pimentel D (1980) Handbook of energy utilization in agriculture. CRC Press, Boca Raton, FL

Platis DP, Anagnostopoulos CD, Tsaboula AD, Menexes GC, Kalburtji KL, Mamolos AP (2019) Energy analysis, and carbon and water footprint for environmentally friendly farming practices in agroecosystems and agroforestry. Sustainability 11:1664

Royan M, Khojastehpour M, Emadi B, Mobtaker HG (2011) Investigation of Energy Inputs for Peach Production Using Sensitivity Analysis in Iran. Energy Convers Manage 64(1):441–446

Salar Ashayeri M, Khaledian MR, Kavoosi-Kalashami M, Rezaei M (2020) Evaluation of energy balance and greenhouse gas emissions in rice cultivation in Guilan province, northern Iran. Paddy Water Environ, 18(1):261–272

Singh S, Mittal JP (1992) Energy in Production Agriculture. Mittal Pub, New Delhi.

Smith P, Bustamante M, Ahammad H, Clark H, Dong H, Elsiddig E, Haberl H, Harper R, House J, Jafari M (2014) Agriculture, Forestry and Other Land Use (AFOLU). Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Snyder C, Bruulsema T, Jensen T, Fixen P (2009) Review of greenhouse gas emissions from crop production systems and fertilizer management effects. Agr Ecosyst Environ 133:247–266

Soltani A, Maleki M, Zeinali E (2014) Optimal crop management can reduce energy use and greenhouse gases emissions in rainfed canola production. International Journal of Plant Production 8:587–604

Toroudi MP, Nouruzi HA, Malidareh AG, Dadashi MR, Dastan S (2018) Evaluation of energy balance and emissions of wheat Triticum aestivum (L production.). Agroecology 9(4):1168–1193

Troujeni ME, Khojastehpour M, Vahedi A, Emadi B (2017) Sensitivity analysis of energy inputs and economic evaluation of pomegranate production in Iran. Inform Process Agricul 5(1):114–123

Tzilivakis J, Warner D, May M, Lewis K, Jaggard K (2005) An assessment of the energy inputs and greenhouse gas emissions in sugar beet (Beta vulgaris) production in the UK. Agric Syst 85:101–119

Vafabakhsh J, Mohammadzadeh A (2019) Energy flow and GHG emissions in major field and horticultural crop production systems (case study: Sharif Abad plain). Agroecology 11(2):365–382

Vahedi A, Zarifneshat S (2021) Evaluation energy flow and analysis of energy economy for irrigated wheat production in different geographical regions of Iran. J Agric Machinery 11(2):505–523

Yapıcıoğlu P, Demir Ö (2021) Minimizing greenhouse gas emissions of an industrial wastewater treatment plant in terms of water–energy nexus. Appl Water Sci 11(12):1–14

Yousefi M, Damghani AM, Khoramivafa M (2016) Comparison greenhouse gas (GHG) emissions and global warming potential (GWP) effect of energy use in different wheat agroecosystems in Iran. Environ Sci Pollut Res 23:7390–7397