ENERGY AND EXERGY UTILIZATION OF SOME AGRICULTURAL CROPS IN TURKEY

by

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Energy and exergy analysis gives valuable information to policy maker in order to make the right decision with regard to agricultural policies. In this present study, an investigation was carried out to reveal the energy and exergy consumption of some agricultural crops cultivated in Turkey for the year of 2014. Wheat, corn, cotton, sunflower, potato and sugar beet are the massively harvested crops in Turkey. Therefore, energy and exergy analysis of these crops were evaluated. The analysis was based on the thermodynamics concept and covers the direct energy usage (i.e. electricity for pumping and diesel fuel for farm machinery) in the agricultural activity. Three different irrigation methods namely, flooding, sprinkler, and drip irrigation were considered. According to the results of the present study, wheat is the most energy and exergy consuming crop and potato is the least energy and exergy consuming crop. In addition to this flooding irrigation method requires the least energy and exergy values. On the other hand, sprinkler irrigation method requires the most energy and exergy values.

Keywords: *Energy, Exergy, Agricultural Crops, Turkey*

1. Introduction

In the modern world, energy policies are aimed to provide the sufficient, cheap and eco-friendly energy in order to support the sustainable development of the societies [1-2]. Agricultural productions are one of the subsidized sectors in the both developed and developing countries. Policy makers make some decisions to improve sustainable development of the agriculture sector [3].

With its favorable geographical conditions and climate, largely arable lands, and abundant water supplies, Turkey is one of the leading countries in the world in the field of agriculture [4]. The geographical features, such as local climatic conditions, fertile soil, and four different seasons with three different floristic zones make Turkey suitable for widespread agricultural products. All these features make agricultural activity important in the economy of Turkey. Therefore, the amount of energy consumed in agricultural sector plays a crucial role in the economy. Consequently, optimization of energy utilization is an important research field.

Many researchers deal with energy utilization in the agricultural sector, and they want to draw attention to the problem of the increase in the consumption of energy in the sector [5-9].

Energy use in agriculture is categorized into two main categories as direct energy use and indirect energy use. Electricity and fuels (gasoline, diesel, coal etc.) are described as the direct energy use. Pesticide, fertilizer, manpower etc. energy sources are also considered indirect energy use [10].

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Researchers investigated the energy consumption of various crops because crops efficiency and quality are related to energy input. However, more reliable and logical policies about the agricultural sector require not only energy analysis but also exergy analysis of the crops, because exergy concept is based on the usefulness of the processed energy in the production [11,12]. Exergy analysis shows the most convenient way among the different usage patterns of energy sources [13].

Some researchers conducted energy and exergy analysis based on the direct energy usage for agricultural sector specific to their countries. Öztürk investigated the energy and exergy efficiencies of the agricultural sector in Turkey [14]. The author indicated the variation of the energy and exergy efficiencies for tractors and pumping stations between the years 1970-1993. Energy and exergy efficiencies were calculated as %74.81-74.97 and %72.32-74.59, respectively. Another energy and exergy analyses of the agricultural sector of Turkey were conducted by Utlu and Hepbaşlı [15]. The authors reported the energy and exergy efficiencies of the years between 1990-2001 as % 27.9-37.4 and % 29.1-41.1, respectively. Similar investigations were conducted in various countries. Ahmed and Jamal evaluated the energy and exergy efficiencies of Jordan as %37.3 and %23.5, respectively [16]. Dinçer et al. investigated the energy and exergy efficiencies of the agricultural sector in Saudi Arabia [17]. The study evaluated the energy and exergy efficiencies as %74.60-74.94 and %69.20-74.19, respectively. Ahamed et al. calculated the energy and exergy efficiencies of the agricultural sector in Malaysia [18]. It was found that the energy and exergy efficiencies were about %22 and %20.72, respectively. In addition to these studies, Hoang and Alauddin compared the exergy extraction between the crop sector and livestock sector in 29 OECD countries [19]. It was concluded that exergy extraction in the crop sector is higher than the livestock sector. In addition to these studies, Chen and Chen discussed the effect of the frequently changed political infrastructure and organization on the agricultural activity in terms of exergy flow of the crops into the society [20].

In this study, the efficiency of the some harvested crops in Turkey was evaluated in terms of energy and exergy analysis. Apart from the other studies, the analyses were performed for some agricultural crops (wheat, corn, cotton, sunflower, potato and sugar beet) grown in Turkey. Wheat, corn, cotton, sunflower, potato and sugar beet are selected for energy and exergy calculation because they are considerably produced in Turkey. Most of the energy consumption in agricultural production is based on direct energy resources such as diesel fuel and electricity. Therefore indirect energy consumption (fertilizer, pesticide, manpower etc.) was disregarded in this study. Diesel fuel (for farm machinery) and electricity (for irrigation pumps) were used as direct energy input into the farming process. Calculations have been performed for the year of 2014. Energy and exergy efficiencies for unit cultivated area were evaluated for each agricultural crop.

In addition to these, the effects of the different irrigation methods (i.e., flooding, sprinkler and drip irrigation) on the energy and exergy efficiencies of the harvested crops were investigated in this context, the irrigation method having the highest energy and exergy efficiencies were determined.

2. Material and Method

Energy and exergy analyses are carried out diesel fuel for shaft work of farm machinery and electricity for water pumping, and hence energy ve exergy efficiencies for agricultural crops are obtained. Statistical data of cultivated area and harvested output are taken from Turkish Statistical Institute, and they are presented in Table 1 [21].

Table 1. Statistical data of some crops for the year 2014 [21].

Crops	Cultivated area (decare)	Harvested output (ton)
Wheat	66 367 448	15 700 000
Corn	6 586 450	5 950 000
Cotton	4 681 429	846 000
Sugar beet	2 887 851	16 742 968
Sunflower	5 524 651	1 480 000
Potato	1 297 032	4 166 000

2.1. Fuel consumption for farm machinery

As the use of machinery increases in agricultural production, diesel consumption increases. In this case, the share of diesel within total production cost also increases. The amount of diesel consumed in agriculture varies according to the crops. The quantities of diesel used per decare have been determined in the production of various crops in Turkey [22]. However, it has been found that a tractor uses 5,024 -7,146 liters of diesel per hour of operation [23]. The tractor is assumed as the farm machine for diesel consumption in the study. The average diesel fuel consumption per decare for various crops is given in Table 2. Density of diesel fuel is taken as 0.84 kg/L [24].

Table 2. Statistical data of diesel fuel consumption values for some crops [22].

Crops	Average diesel fuel consumption (L/decare)	Total diesel fuel consumption (L)	Total diesel fuel consumption (kg)
Wheat	6.54	434 043 109.92	364 596 212.33
Corn	11.88	78 247 026	65 727 501.84
Cotton	20.76	97 186 466.04	81 636 631.47
Sugar beet	12.18	35 174 025.18	29 546 181.15
Sunflower	7.5	41 434 882.5	34 805 301.3
Potato	23.28	30 194 904.96	25 363 720.16

2.2. Electricity consumption for irrigation

Average water consumption values (mm) of agricultural products were determined in Turkey conditions [25]. The water consumption values per hectare (ha.mm) according to Table 3 are given in Table 5.

Table 3. Statistical data of water consumption values for some crops. [25].

Crops	Average water consumption (mm)	Total water consumption (ha.mm)
Wheat	540	3 583 842 192
Corn	790	520 329 550
Cotton	900	421 328 610
Sugar beet	965	278 677 621.5
Sunflower	460	254 133 946
Potato	715	92 737 788

The energy inputs used in the irrigation process consist of diesel fuel, electric energy, and system equipment inputs [26]. Diesel fuel and electric energy are called direct energy, and indirect energy input to system equipment [27-29]. In this study, electric energy was accepted for irrigation. There is a number of researchers' work on electricity energy spent in agricultural irrigation [30-36]. In this study, the coefficients developed by Collins for the electric energy used in the irrigation were utilized [34]. However, a number of irrigation methods are possible for selected plants; Flood, rain, and drip irrigation methods have been studied in this study. Collins proposed that if the surface water sources are used, required energy are 3.72 MJ/ha.mm, 21.1 MJ/ha.mm and 6.2 MJ/ha.mm for flooding, sprinkler, and drip irrigation, respectively [34].

2.3. General balance equations

In steady state condition, energy and exergy balance equations are described as following respectively [37]:

$$\sum_{in} (h + ke + pe)_{in}\dot{m}_{in} - \sum_{out}(h + ke + pe)_{out}\dot{m}_{out} + \sum_r Q_r - W = 0 \quad (1)$$

$$\sum_{in} \varepsilon_{in}\dot{m}_{in} - \sum_{out} \varepsilon_{out}\dot{m}_{out} + \sum_r E^Q - E^W - I = 0 \quad (2)$$

The meanings of the terms in equations (1) and (2) above are: m_{in} and m_{out} mass input and output; *Q* and *W* are heat transfer and work respectively; heat transfer and work, respectively, associated with E^Q and E^W exergy transfer; $\mathcal{E}$ is the specific exergy; *I* is the exergy destruction; *h*, *ke*, and *pe* represent enthalpy, kinetic energy, and potential energy, respectively. The system is considered as a closed system, i.e. $\dot{m}_{in} = \dot{m}_{out} = 0$ and Eq. (1) and (2) can be simplified to:

$$\sum_r Q_r - W = 0 \quad (3)$$

$$\sum_r E^Q - E^W - I = 0 \quad (4)$$

For reference state, fossil fuels have almost zero physical exergy so the exergy content of diesel fuel just contains the chemical exergy [17].

$$\varepsilon_{ff} = H_{ff}\gamma_{ff} \quad (5)$$

In Eq. 5, γ_{ff} is defined as quality factor of fuel which is the ratio between chemical exergy (ε_{ff}) and higher heating value of fuel (H_{ff}) of fuel. Chemical exergy, higher heating value of fuel and quality ratios are taken as 42265 kJ/kg, 39500 kJ/kg and 1.07, respectively [38].

2.4. Energy and exergy efficiencies

The efficiencies defined by taking the first and second laws of thermodynamics are generally called energy and exergy efficiencies [14]. Average energy and exergy efficiencies are evaluated by using consumed direct energy sources and their conversion efficiencies. Energy and exergy efficiencies can be defined as follows [16-18].

$$\eta = \frac{\eta_{Tractor}\, x Energy\ of\ fuel\ consumption + \eta_{Pump}\ x\ Electricity\ consumption}{Total\ energy\ consumption} \quad (6)$$

$$\Psi = \frac{\Psi_{Tractor}\, x Exergy\ of\ fuel\ consumption + \Psi_{Pump}\ x\ Electricity\ consumption}{Total\ exergy\ consumption} \quad (7)$$

Shaft work (W) is produced in work production processes that are carried out using electric energy and fossil fuel [14]. As the output of the agricultural machinery, the shaft work takes place in kinetic energy form. Energy efficiency of a partially loaded tractor (most common type of farm machinery) is taken as 75% [17]. It means that 75% of chemical energy is converted to mechanical shaft work. It is assumed that chemical energy directly converted to shaft work; therefore exergy efficiency of a tractor (Eq. 8) is considered as same with the energy efficiency of a tractor.

$$E^{W} = W \quad (8)$$

Energy and Exergy efficiencies for tractors (Eq. 9 and 10) are evaluated by using generated shaft work and required chemical energy and exergy.

$$\eta_{tractor} = \frac{W}{m_f H_f} \quad (9)$$

$$\Psi_{tractor} = \frac{E^{W}}{m_f \varepsilon_f} = \frac{W}{m_f \gamma_f H_f} \quad (10)$$

In the production of electric shaft work for pumps, energy and exergy efficiencies are defined as follows. The energy efficiency of a pump is defined as

$$\eta_{pump} = \frac{W_{reversible}}{W_{actual}} \quad (11)$$

And exergy efficiency

$$\Psi_{pump} = \frac{W}{W_e} \quad (12)$$

Energy and exergy efficiencies are taken as 70% and 2.85% for a standard pump used in agricultural processes [17].

3. Results and Discussion

The aim of this study is to evaluate direct energy use (diesel fuel for shaft work and electricity for water pumping) in different agricultural products by energy and exergy analysis. However, the effects of different irrigation methods on energy and exergy productivity of harvested agricultural crops are investigated. Energy and exergy consumption of farm machinery are illustrated in Table 4 and Figure 1. Estimated exergy consumption for diesel fueled farm machinery was prepared from equation (5). According to the results, wheat cultivation required the most energy and exergy values. The main reason for this result is that the cultivated area (66 367 448 decare) is more than the others. Potato cultivation is required less energy and exergy consumption than other. Potato cultivation is required most diesel fuel (23.28 L/decare), however, cultivated are (1 297 032 decare) is the least.

Table 4. Estimated energy and exergy consumption for farm machinery (diesel fuel).

Agricultural crops	Energy usage (PJ)	Exergy usage (PJ)
Wheat	14.4016	15.4097
Corn	2.5962	2.7780
Cotton	3.2246	3.4504
Sunflower	1.3748	1.4710
Potato	1.0019	1.0720
Sugar beet	1.1671	1.2488

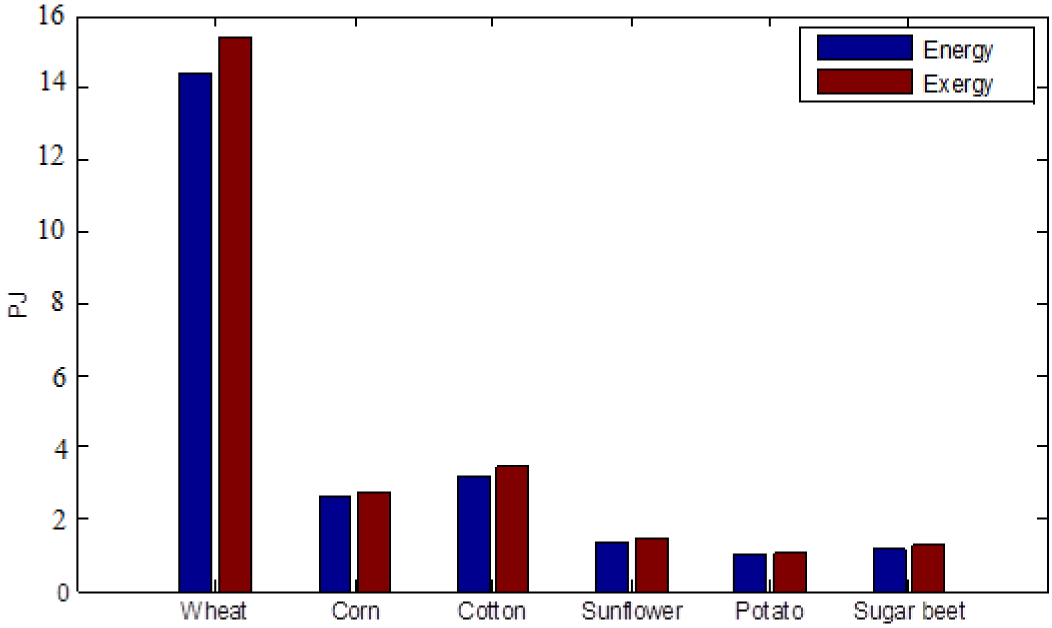

Figure 1. Estimated energy and exergy consumption for farm machinery (diesel fuel).

The effects of the different irrigation methods (flooding, sprinkler, and drip irrigation) on the energy and exergy efficiencies of the harvested crops were investigated with this study. Water is one of the most important inputs in agricultural production. For this reason, it is necessary to make irrigation in agricultural production. Irrigation is the practice of applying to the soil with different irrigation methods when the plant cannot be met by the rainwater it needs. Irrigation method is the application of irrigation water to soil [25]. Based on Collins' calculation, the estimated energy consumption of selected plants according to different irrigation methods (flooding, sprinkler, and drip irrigation) is given in Table 5 and Figure 2. The value of consumed electricity energy is the same as the exergy value. For this reason, the electricity energy consumed for irrigation is the same as the exergy value [18]. According to the results, flooding irrigation is the lowest-energy intensity irrigation method. However, it leads high water consumption, and it may degrade the soil. Sprinkler irrigation is the highest-energy intensity irrigation method due to extensive piping on the field and high water mass flow rate. Increasing piping leads pressure drop in the piping system, and it requires more pumping power. On the other hand, drip irrigation requires less water, hence pumping power is less than sprinkler irrigation.

Energy and exergy intensity for irrigation is most at wheat farming and the least at potato farming. Certainly, potato requires almost 32% more water (Table 3) but cultivated area is 60 times fewer.

Tablo 5. Energy consumption for different irrigation methods (flood, sprinkling, and drip irrigation) in agricultural products

Agricultural Products	Energy consumption (PJ)		
	Flooding irrigation	Sprinkler irrigation	Drip irrigation
Wheat	13.331	75.619	22.219
Corn	1.935	10.978	3.226
Cotton	1.567	8.890	2.612
Sugar beet	1.036	5.880	1.727
Sunflower	0.945	5.362	1.575
Potato	0.344	1.956	0.574

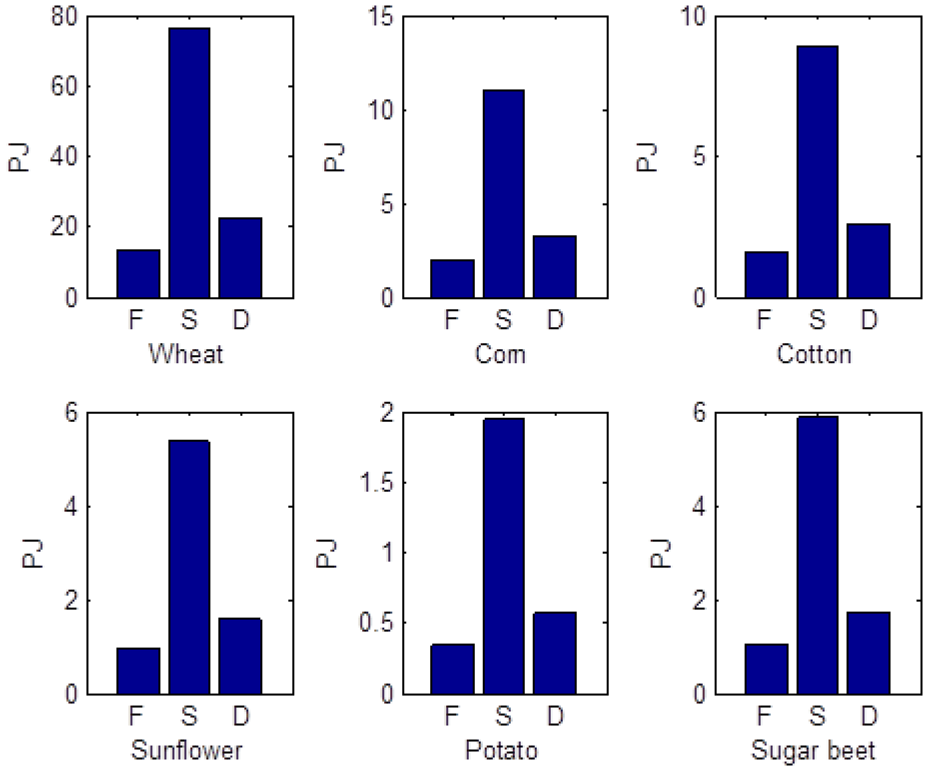

Figure 2. Estimated energy consumption for different irrigation methods (F: Flooding irrigation, S: Sprinkler irrigation, D: Drip irrigation).

Total Energy and Exergy efficiencies (electricity for irrigation and diesel fuel for farm machinery) of the crops are indicated in Table 6 and Figure 3. The calculation for determining energy and exergy efficiencies of agriculture crops is given below. The following calculation belongs to energy and exergy efficiency for corn production according to drip irrigation method.

$$\eta = [(75 \times 2\,596) + (70 \times 3\,226)] / [(2\,596 + 3\,226)] = \%72.23 \quad (13)$$

$$\Psi = [(75 \times 2\,777) + (2.85 \times 3\,226)] / [(2\,777 + 3\,226)] = \%\,36.23 \quad (14)$$

In general, Exergy efficiencies are less than energy efficiencies for all crops. The main reason of that is the irreversibility in the pumping process of the irrigation. Flooding irrigation seems to be the most exergy efficient irrigation methodology. On the other hand, it leads to waste much water because of the evaporation, runoff, and infiltration of water in uncultivated areas. This irrigation technique also causes the increase in soil salinity. Sprinkler irrigation technique has the least exergy and energy efficiencies. However, this technique requires the pressurized water at the end of the sprinklers and high water mass flow rate compared to drip irrigation technique. Therefore, it needs more pumping power.

Potato farming is the most energy and exergy efficient farming. Energy and exergy efficiencies are found as 73.72% and 57.43% for flooding irrigation, 71.69% and 28.39% for sprinkler irrigation, 73.18% and 49.81% for drip irrigation, respectively. Wheat farming is the least energy and exergy efficient farming. Energy and exergy efficiencies are found as 72.58% and 41.33 for flooding irrigation, 70.79% and 14.95 for sprinkler irrigation, 71.95% and 32.20% for drip irrigation, respectively.

Table 6. Estimated energy and exergy efficiencies (electricity for irrigation and diesel fuel for farm machinery) of the selected crops.

Wheat	Flooding irrigation+Diesel fuel	Energy efficiency	0.7258
		Exergy efficiency	0.4133
	Sprinkler irrigation+Diesel fuel	Energy efficiency	0.7079
		Exergy efficiency	0.1495
	Drip irrigation+Diesel fuel	Energy efficiency	0.7195
		Exergy efficiency	0.3220
Corn	Flooding irrigation+Diesel fuel	Energy efficiency	0.7286
		Exergy efficiency	0.4537
	Sprinkler irrigation+Diesel fuel	Energy efficiency	0.7096
		Exergy efficiency	0.1742
	Drip irrigation+Diesel fuel	Energy efficiency	0.7223
		Exergy efficiency	0.3623
Cotton	Flooding irrigation+Diesel fuel	Energy efficiency	0.7336
		Exergy efficiency	0.5246
	Sprinkler irrigation+Diesel fuel	Energy efficiency	0.7096
		Exergy efficiency	0.2302
	Drip irrigation+Diesel fuel	Energy efficiency	0.7276
		Exergy efficiency	0.4391

Sunflower	Flooding irrigation+Diesel fuel	Energy efficiency	0.7296
		Exergy efficiency	0.4677
	Sprinkler irrigation+Diesel fuel	Energy efficiency	0.7102
		Exergy efficiency	0.1838
	Drip irrigation+Diesel fuel	Energy efficiency	0.7233
		Exergy efficiency	0.3769
Potato	Flooding irrigation+Diesel fuel	Energy efficiency	0.7372
		Exergy efficiency	0.5743
	Sprinkler irrigation+Diesel fuel	Energy efficiency	0.7169
		Exergy efficiency	0.2839
	Drip irrigation+Diesel fuel	Energy efficiency	0.7318
		Exergy efficiency	0.4981
Sugar beet	Flooding irrigation+Diesel fuel	Energy efficiency	0.7265
		Exergy efficiency	0.4227
	Sprinkler irrigation+Diesel fuel	Energy efficiency	0.7083
		Exergy efficiency	0.1519
	Drip irrigation+Diesel fuel	Energy efficiency	0.7202
		Exergy efficiency	0.3312

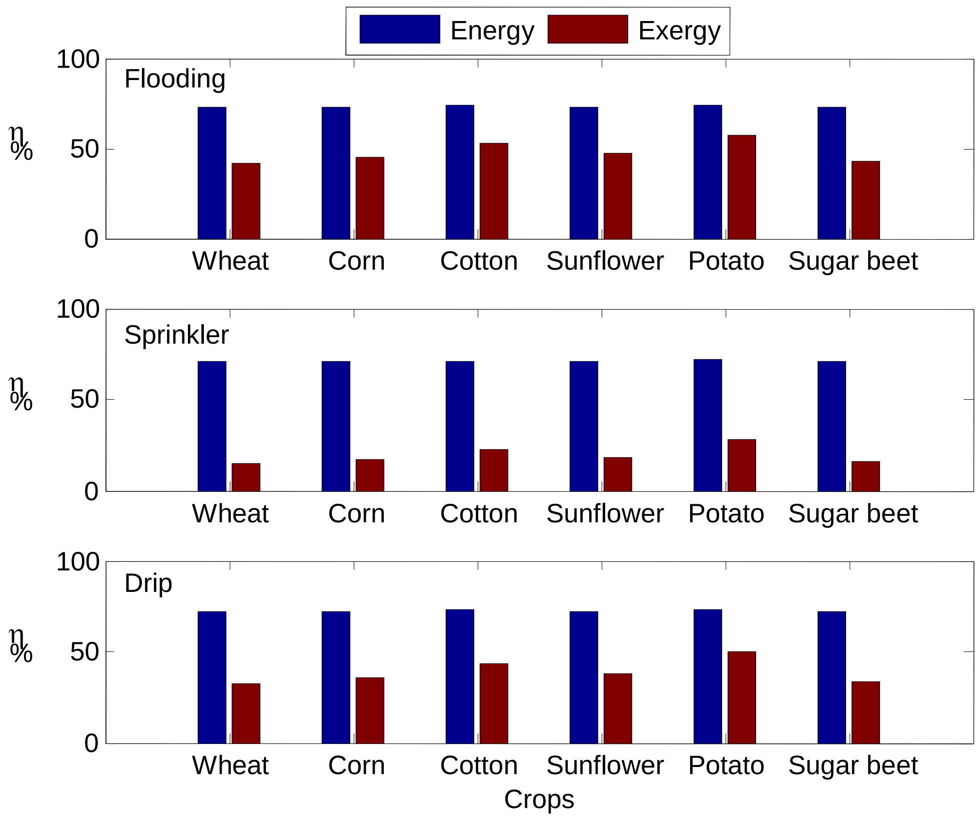

Figure 3. Estimated energy and exergy efficiencies (electricity for irrigation and diesel fuel for farm machinery) of the selected crops.

4. Conclusion

In this study, energy and exergy analysis were conducted for some field crops (Wheat, corn, cotton, sunflower, potato and sugar beet) cultivated in Turkey. Total consumption of the direct energy uses (diesel fuel and electricity) was calculated to explore the energy and exergy efficiencies of the crops. However, the effects of different agricultural irrigation methods (eg flood, sprinkling, and drip irrigation) on the energy and exergy efficiencies of the harvested crops were investigated. The following conclusions can be drawn from the present study:

- Wheat farming consumes the most diesel fuel proportionate to the massive cultivated area. On the other hand, potato consumes the least diesel fuel. Therefore, maximum and minimum chemical energy and exergy consumption are found for wheat and potato, respectively.
- Wheat farming also consumes the most water, and it leads to increase in the electricity consumption. On the contrary, potato farming consumes the least water and its electricity consumption is very low compared to the other crops farming. Therefore maximum and minimum electricity consumption are found for wheat and potato, respectively.
- Flood irrigation is the most energy and exergy efficient irrigation method, conversely, sprinkler is the least energy and exergy efficient irrigation method. However, it is well-known that flood irrigation method causes the increase in the salinity of the soil.

Nomenclature

E^W exergy work (J/s)
E^Q exergy heat (J/s)
H higher heating value (KJ)
h specific enthalpy (kJ/kg)
I exergy destruction (J)
$\dot{m}$ mass flow rate (kg/s)
W shaft work (W)

Greek letters

Ɛ specific exergy (J/kg)
η energy efficiency
Ψ exergy efficiency
γ exergy grade function

Indices

in inlet
out outlet
ff fuel

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