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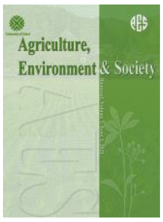

Role of mechanization on the sustainability of sugar beet production using emergy approach

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ABSTRACT

Over 40% of agriculture on the planet is conducted on smallholder farms with low productivity but high production costs. As a result, governments have attempted to replace traditional farms with mechanized farms in recent years. The sustainability of three distinct production systems, namely traditional, semi-mechanized, and mechanized cultivation systems, were assessed using emergy approach in 2017-2018. These systems were practiced over areas of less than 2 ha, 2-10 ha, and more than 10 ha, respectively. The results indicated that the total emergy values for sugar beet production were 2.84E+16, 4.57E+16, and 6.21E+16 sej ha^{-1} yr^{-1}, respectively, for traditional, semi-mechanized, and mechanized systems. Historically, the proportion of renewable natural inputs, non-renewable natural inputs, and purchased inputs in total input emergy was 8.88E+14, 8.88E+15, and 1.86E+16 sej ha^{-1} yr^{-1}, respectively. However, the proportion of renewable natural inputs, non-renewable natural inputs, and purchased inputs was 9.06E+14, 2.56E+16, and 3.57E+16 sej ha^{-1} yr^{-1}, respectively, in mechanized farms. As the rate of mechanization increased, the unit emergy value, renewable emergy ratio, emergy exchange ratio, emergy yield ratio, emergy input ratio, and environmental loading ratio increased by 11.5, 77, 13.7, 11.9, and 1.32 percent, respectively; while the renewable emergy ratio and environmental sustainability index decreased by 20.1 and 28.9 percent, respectively. In general, the results indicated that mechanization protected the environment more than traditional cultivation.

Highlights

- Emergy approach was used to analyze the sustainability of three separate production systems: traditional, semi-mechanized, and mechanized.
- The overall emergy values for traditional, semi-mechanized, and mechanized sugar beet were 2.84E+16, 4.57E+16, and 6.21E+16 sej ha-1 yr-1, respectively.
- As the rate of mechanization increased, the UEV, R%, EER, EYR, EIR, and ELR increased; whereas the ESI index decreased.

1. Introduction

The agricultural sector serves as the largest trusted source of food production and security in society (Jelsøe. and Kjærgård, 2016). With the increasing population and rising demand for food urging farm labor recruitment from any other economic sector due to labour force migration from the agricultural sector, the use of machine labor has become commonplace for numerous of the most demanding agricultural activities. Agricultural mechanization is the use of machinery in the different stages of agricultural and livestock production in order to increase production speed, decline costs, reduce production time, facilitate operations, optimize agricultural inputs, and augment production in general (Kohansal and Mansoori, 2013). Mechanization is the basic condition representing the transition from traditional farming to modern farming. Catering to the needs of the current growing population and, in general, preventing the global food security crisis will not be possible by resorting to traditional methods. Over a 35% increase in crop production and a 50–60% decrease in production resulted from mechanization.

It is believed that the agricultural labor force will become scarce and costly, and production costs in this sector will increase in the future. Therefore, the research path in this field is tending towards alleviating labor

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dependency and production costs and enhancing sustainable productivity (Schmitz and Moss, 2015). In this regard, agricultural mechanization is a critical factor for achieving highly efficient production and helping feed the growing population on earth. This technology has made the production of agricultural products more valuable through the more efficient use of labor, as well as timely operations and input management (Bagheri and Moazzen, 2009). According to the studies, agricultural mechanization increases crop yield, cultivated land area, labor productivity and use inside and outside agricultural lands (such as in machinery manufacturing industries), the profitability of crop production through timely and efficient production, and optimal uses of inputs and outputs (Moazzen, 2010). However, some researchers maintain that excessive applications of machinery and non-renewable resources like fossil fuels and fertilizers for producing more agricultural products endanger the sustainability of agricultural systems (Araujo et al., 2013).

Over the past decades, commercial farming has replaced traditional farming as the dominant mode of agricultural production in Iran (Tabar et al., 2010). Modern farming systems include ecosystems controlled by humans. These systems, on the one hand, are based on environmental inputs such as light, wind, water, and soil, and on the other hand, on such inputs as fertilizers, pesticides, fuel, electricity, equipment, and machinery that are purchased by farmers and included as economic inputs (Bazrgar et al., 2011). Demands for more food production have led to the use of chemical fertilizers, pesticides, agricultural machinery, and environmental resources like land and water resources extensively utilized in food production. Standard agricultural systems are highly dependent on intensive energy consumption, which is one of the main causes of such problems as global warming in most developed and developing countries (Notarnicola et al., 2017). Unfortunately, most of the time, farmers consume more energy to increase crop production, yet they do not know enough about how to enhance energy consumption efficiency (Ozkan et al., 2004). Increasing the use of environmental resources is incompatible with the sustainability of production systems. Any system using more environmental resources, especially non-renewable ones, would be less sustainable in any way (Hanif et al., 2019). Sustainability in agriculture is the ability to maintain and sustain long-term production and successful resource management to meet changing human needs, preserve environmental qualities, and protect natural resources (Jelsøe and Kjærgård, 2016).

Today, sustainability has become one of the most common terms in economic science, social science in general, and environmental science in particular (Moore et al., 2005). Accordingly, the ecosystem of agricultural systems must be carefully designed and managed so that optimal productivity and sustainability can be maintained by the improved systems. Production stability measurement is a quantitative approach to determining the desirable or undesirable effects of changes in a system. Among the different methods of measuring production sustainability, the use of emergy analysis technique as a suitable approach has been of interest to researchers. Emergy is a type of energy analysis that measures all the sources of the biosphere and human activities that are directly and indirectly utilized to obtain a particular product (Brown et al., 2016). Emergy analysis is an ecological estimation method that comprehensively estimates all the inputs, including energy, consumed natural resources, and financial and human costs, by using units of emergy usually measured in solar energy units (Odum et al., 2000). The impacts of mechanization on the stabilities of production systems using emergy analysis have not been investigated so far. Nonetheless, the emergy analyses of various production systems differing in the amounts of resources focused on many types of research. In their study, Ortega reported more sustainable soybean cultivation based on the biologic (ecological and organic) system than the industry (agrochemical and no-till using herbicide). Martin et al. (2006) compared three agricultural systems, including two conventional maize and blackberry cropping systems and one domestic system. They found that fertilization and irrigation of corn production (95% of purchased emergy input) were the most significant emergy inputs across the three systems. Sustainability indices for the corn, blackberry, and indigenous systems were determined to be 0.06, 0.65, and 115.98, respectively. Despite its high stability, the energy yields of the indigenous system were 14 and 53 times less than those of the blackberry and corn systems. In the two substantial and commercial rapeseed systems, it was reported that the ecological sustainability of a commercial rapeseed production system could be ameliorated by improving soil organic matter and preventing its degradation (Amiri et al., 2019). Evaluations of 12 different maize production systems under varied (low, high, and bio-tech) input intensities showed that the total amounts of emergy were enhanced by increasing the input levels. Accordingly, the total emergy in the low-input systems was 3.37E+15 sej ha-1 yr-1, whereas it was increased by 11.73 E+15 sej ha-1 yr-1 (248%) in the biotech production systems (Ortega et al., 2005). In the different bean production systems based on ecological, integrated, and low, medium, and high-input management practices, Asgharipour et al. (2019) reported that the ecological cropping systems had more sustainability and fewer more minor environmental impacts compared to high-yield cropping systems. Ecological production systems have provided more ecosystem services than other cropping systems. In a study on the emergy assessments of five different maize production systems (control, chemical fertilizer, poultry manure biochar, rice hull biochar, and sugarcane filter press), it was reported that the most emergy was consumed in the corn production with poultry manure biochar. Stability was higher for the systems with more renewable sources and fewer purchased inputs (Moonilall et al., 2020). Jiang et al. (2007) using emergy analysis, the sustainability and development of China's agricultural system were examined, and Chinese agriculture was reported to occur in a transitional stage from traditional to modern systems. Meanwhile, the pressure on natural resources was increased by consuming such resources as soils, fuels, and fertilizers. According to the results of this research, the total flow of emergy applied in Chinese agriculture based on the environment and economy had increased from 2000 to 2004.

Sugar beet (Beta vulgaris L.) is one of the strategic products, and together with sugar cane, serves as the primary source of sugar production. The sugar content of sugar beet is higher than that of sugar cane (about 25%). About a quarter of the sugar produced in the world comes from sugar beet. In addition to sugar production, this product has some by-products, such as pulp and molasses, which are used for animal feed and in the industry, respectively (Erdal et al., 2007). Khorasan Razavi (21%), Fars (13.8%), Kermanshah (6.5%), Hamadan (3.8%), and Lorestan (3.6%) Provinces have the first to fifth ranks of sugar beet production in Iran, respectively (Anonymous, 2021). These five provinces account for 83.3% of sugar beet production in Iran. Sugar beet is cultivated in Iran on very small farms (less than one hectare) and large farms (more than 50 hectares). Small farm cultivation is primarily dependent on family labor and the use of livestock manures and renewable environmental resources, whereas large farm cultivation is primarily dependent on machinery and the use of non-renewable environmental resources such as chemical fertilizers. Today, the tendency to use mechanization in agricultural lands is greatly expanding. The use of mechanization will be accompanied by a change in energy consumption per unit area. Therefore, this study was conducted to evaluate the sustainability of sugar beet production based on different production systems.

2. Materials and methods

2.1. Study area description

Jouvin County is located at 57◦ 34' East latitude and 36◦ 22' North longitude, with a height of 980 m above sea level. The average monthly temperature in the city varies from -3 ◦C in January to 40 ◦C in July, with an annual average temperature of 17.8 ◦C. Its average annual wind speed and average rainfall are 3.2 ms-1 and 250 mm, respectively.

Face-to-face questionnaires were used to collect data for this study from farmers in traditional and semi-mechanized farms, as well as experts from Barakat Agricultural Company in mechanized farms. Cochran's formula based on Eqs. 1 and 2 was applied to determine the number of samples (Cochran, 1997).

$$n = \frac{N(s \times t)^2}{(N-1)d2 + (s \times t)^2} \quad \text{Eq. 1}$$

$$n = \frac{t \times s}{\sqrt{n}} \quad \text{Eq. 2}$$

In these Eqs., t: 1.96 (95% confidence level), s: prediction of community standard deviation, d: optimal probability accuracy, n: community volume, and n: sample size.

In this research, 67, 20, and 5 farms were investigated for traditional, semi-mechanized, and mechanized systems (all fully mechanized farms), respectively. The definitions of traditional, semi-mechanized, and mechanized fields were determined based on Bazrgar's study (2011). A summary of field operations in the three planting systems is given in Table 1.

Table 1. Characteristics of sugar beet production systems

Operations	Subnational	Semi-mechanized	Mechanized
Average area	<2	2-15	>15
Planting date	5April- 5 May	20 March- 9 April	1 March-15 March
Machinery used	Moldboard plow, disc plow, leveler, Chisel, Seed drills	Subsoiler, moldboard plow, disc plow, leveler, Chisel, Sprayer, Seed drills and manual harvester	Subsoiler, moldboard plow, disc plow, leveler, Manure spreaders, Chisel, Sprayer, Seed drills and Sugar beet harvester
Harvesting period	December-July	December-May	November-May

2.2. Emergy analysis method

The first step in analysing emergy was to designate the spatial and temporal boundaries of the investigated systems and draw an emergy diagram to classify the inputs of the systems into renewable, non-renewable, local, and imported sources. Figure. 1 shows the cumulative emergy flow diagram for the production systems in this study. The driving inputs to the agricultural system come from two sources: environmental inputs and inputs from the human economy. In our model, the rectangular box displays the system's boundaries. On the left and right sides of the model, the natural inputs and valuable performance of the manufacturing systems are shown, respectively, while market inputs are listed at the top.

To analyze the production systems and calculate the indices, the inputs were divided into four types (Odum et al., 2000): free renewable environmental inputs (R), such as sun, rain, and wind; non-renewable environmental inputs (N), such as irrigation water, soil erosion, and soil organic matter losses; non-free renewable inputs (FR), such as seeds and manure purchased; and non-free inputs (FN), such as fertilizer, pesticide, machinery, fuel, and electricity.

To obtain the emergy value of each input, the raw information of each input was multiplied by their conversion coefficients in terms of joules, grams, or IR Rials. Total emergy was the sum of all energies from all the independent inputs. Finally, emergy indices were calculated and interpreted to evaluate the systems (Table 3).

After calculating all the input and output currents of emergy and materials for each production system, the obtained values were converted into units of emergy (sej) by multiplying their corresponding coefficients. These conversion coefficients were adapted for each item from the previous studies. Different conversion coefficients were calculated for each case based on the varied sources.

The coefficients were selected from the studies that were most similar to the conditions of this study (Agostinho et al., 2008; Amiri et al., 2019, 2020; Asgharipour et al., 2019; Moonilall et al., 2020; Odum et al., 2000).

Various emergy-based indices have been used to assess the environmental, ecological, and economic status of systems. The indices utilized in this research are presented in Table 2.

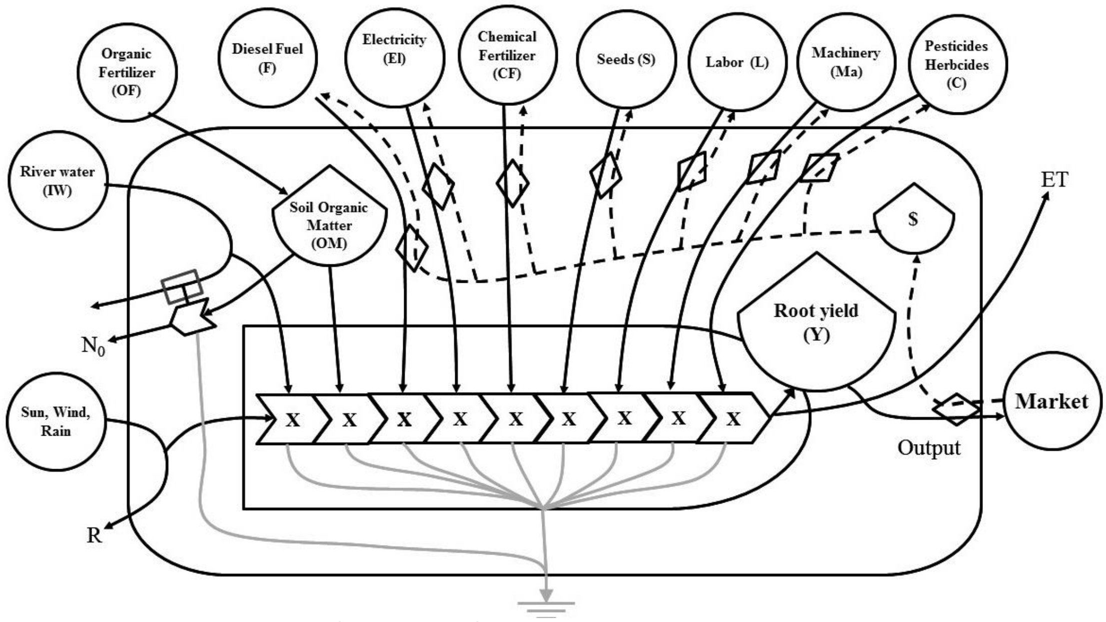

Figure 1. Emergy flow diagram of the sugar beet production systems in Jouvin, Iran.

Table 2. Indicators used to compare different sugar beet production systems

Indices	Formula	Specifications
Renewable environmental inputs	R	Local potentially renewable flows
Non-renewable environmental inputs	N	Local potentially renewable flows from free local resources that are being used in a non-renewable manner
Renewable purchased inputs	F_R	Renewable flows from purchased resources
Non-renewable purchased inputs	F_N	Non-renewable flows from purchased resources
Economic yield (J ha^{-1} or g ha-1)	E	Root yield of crops sold on the market
Market value of the economic yield (Rials g^{-1})	Y_M	Money received for the crops when sold.
Total emergy input	$U = R + N_0 + F_R + F_N$	Total emergy resources required to support the production system
Total emergy output	$Y = R + N_0 + F_R + F_N$	Total emergy of system products
Unit emergy value for economic yield	UEV =U / E (sej J^{-1})	Amount of emergy required to produce an economic output in joules, a measure of system efficiency.
Specific emergy	SE = U / W	Amount of emergy required to produce an output unit measured in grams. W is the accessible weight of the product.
Emergy renewability	$\%R = (R+F_R) / U$	Percentage of renewable emergy used by the system
Emergy exchange ratio	$EER_Y = Y_M / U$	Emergy exchange ratio based on crop yield per unit area
Emergy yield ratio	$EYR = U / F_R+F_N$	Ability of a process to use local renewable and non-renewable resources when economic resources from outside are invested in the system as a capital input.
Environmental loading ratio	$ELR = (N+F_N) / (R+F_R)$	The ratio of non-renewable emergy to renewable emergy used by the system. ELR* is an inverse measure of the sustainability of the system.
Emergy sustainability ratio	ESI = EYR / ELR	The ratio of system yield per unit of purchased input to the total loading on the local system. Systems with higher yields and lower loadings are more sustainable.
Emergy investment ratio	EIR = (FN + FR) / R	The ratio of purchased resources to renewable environmental resources, alone.

3. Results and discussion

3.1. Emergy flow structure in various production systems

3.1.1. Renewable environmental resources

Renewable sources in the three cropping systems studied are shown in Tables 3 and 4. As the intensity of mechanization increases, the percentage of use of renewable resources in the agricultural system declines. The highest share of the renewable environmental resources usage was observed in traditional cultivation, which was 51.20% and 114% more than semi-mechanized and mechanized cultivation, respectively (Figure. 2). The higher share of environmental renewables in the traditional cropping system can be attributed to the lower share of purchased resources compared to the other two cropping systems.

Table 3. Natural and economic flows of different production systems of sugar beet (units. ha^{-1}). The unit and the renewability factor (fraction renewable energy)

		Ren Factor	Traditional	Semi-mechanized	Mechanized
Renewable environmental inputs					
Solar energy	J	1	3.97E+13	4.05E+13	4.41E+13
Wind, kinetic energy	J	1	8.64E+10	9.25E+10	1.04E+11
Rain, chemical energy	J	1	2.89E+10	3.04E+10	2.94E+10
Evapotranspiration	J	1	2.95E+10	3.28E+10	2.99E+10
Non-renewable environmental inputs					
SOM reduction	J	0	6.96E+10	1.23E+11	1.23E+11
Soil erosion	g	0	6.00E+05	6.00E+05	6.00E+05
Irrigation	J	0	8.33E+09	6.91E+10	6.91E+10
Purchased inputs					
Human labour	J	0.1	1.89E+09	1.16E+09	9.43E+08
Machinery	g	0	1.34E+03	4.59E+03	1.54E+04
Fossil fuel and lubricants	J	0	5.98E+09	1.35E+10	1.65E+10
Nitrogen fertilizer	g	0	8.28E+04	1.38E+05	1.84E+05
Phosphorus fertilizer	g	0	8.14E+04	9.20E+04	8.05E+04
Potash fertilizer	g	0	7.15E+04	7.50E+04	7.50E+04
Boron fertilizer	g	0	0.00E+00	0.00E+00	2.00E+04
Micro fertilizer			4.00E+03	8.00E+03	8.00E+04
Organic fertilizer	g	0.8	2.00E+07	2.00E+07	6.00E+07
Pesticide	g	0	1.25E+03	3.50E+03	3.50E+03
Herbicide	g	0	2.00E+03	4.00E+03	7.00E+03
Electricity	J	0.01	7.20E+12	1.15E+13	1.22E+13
Installation of irrigation system	Rials	0.20	0.00E+00	3.00E+06	4.66E+06
Seed	Rials	0.43	4.80E+06	2.40E+06	2.40E+06
Output					
Root yield	g		5.60E+07	9.00E+07	1.10E+08
Root yield	J		9.13E+11	1.47E+12	1.79E+12

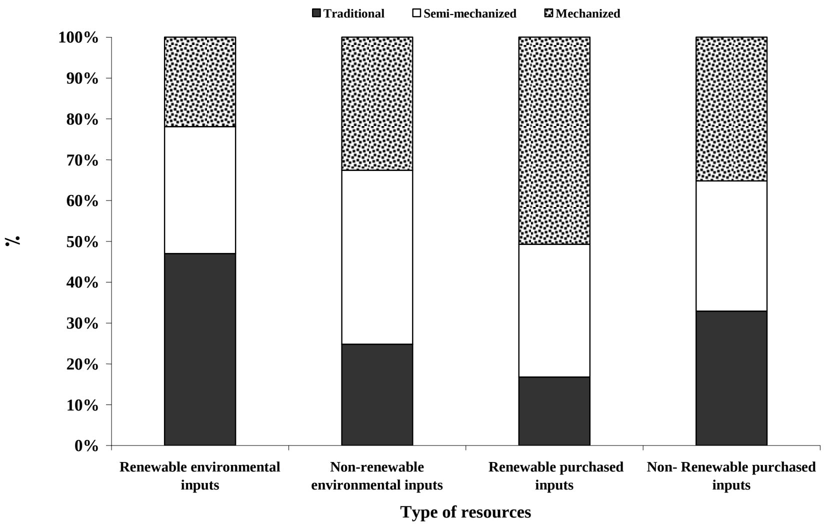

Figure 2. Structure of emergy inputs category for three sugar beet production systems.

In mechanized cultivation, due to the longer crop growth period due to the earlier cultivation date in this system, the solar energy (4.41E + 13 sej) was higher compared to the other two systems. In five corn production systems with different amendment applications, it was shown that the renewable environmental resources used in all cropping systems were almost similar. However, in corn production systems where biofuels were used, the share of environmental renewables was greater due to the use of more manpower and the renewables used in biofuel production (Moonilall et al., 2020). It has been reported that farming operations, such as planting at the right date or using longer-growing cultivars would make more use of environmental resources (Amiri et al., 2019; Amiri et al., 2020).

3.1.2. Non-renewable environmental resources

Semi-mechanized cultivation had the highest share of emergy (53.86%), and traditional cultivation had the lowest share of emergy (31.32%) from non-renewable environmental sources (Table 3, 4). In traditional cultivation, soil organic losses, and in semi-mechanized and mechanized cultivation, irrigation water had the highest share of non-renewable environmental resources. The share of organic losses in traditional cultivation was 22.98% of total emergy, and the share of irrigation water in semi-mechanized and mechanized cultivation was 27.93% and 21.35% of total emergy, respectively. In both semi-mechanized and mechanized planting systems, soil organic losses and erosion were almost equal. However, in mechanized cultivation, due to more water consumption during the growing period, the amount of irrigation water was higher than in semi-mechanized cultivation. Traditional cultivation had a lower organic loss rate than semi-mechanized and mechanized cultivation, which seems due to the reduced use of agricultural machinery and fewer variations in soil microbial flora that play a major role in soil organic matter degradation. Similar results have been reported by Amiri et al. (2019) who found that commercial canola cultivation had 86.36% more soil organic losses than traditional cultivation. The use of High-yield cultivars, single-crop cultivation, weed removal, herbicide application, and more intensive tillage operations were the main reasons for more soil losses in commercial cultivation.

Table 4. Emergy synthesis and input structure of Sugar beet in different production systems (sej ha^{-1}) except as noted

	Unit	Transformity	Refs. for transformity	Emergy (sej ha^{-1})					
				Traditional		Semi-mechanized		Mechanized	
				Quantity	%	Quantity	%	Quantity	%
Renewable environmental inputs									
Solar energy	J	1.00E+00	Definition	3.97E+13	0.14	4.05E+13	0.09	4.41E+13	0.07
Wind, kinetic energy	J	1.25E+03	Campbell, and Erban, 2017	1.08E+14	0.38	1.16E+14	0.24	1.30E+14	0.21
Rain, chemical energy	J	2.25E+04	Campbell (man.)	6.51E+14	2.30	6.85E+14	1.44	6.62E+14	1.06
Evapotranspiration	J	2.88E+04	Campbell (man.)	8.49E+14	2.99	9.44E+14	1.99	8.62E+14	1.39
				8.88E+14	**3.13**	**9.85E+14**	**2.07**	**9.06E+14**	**1.46**
Non-renewable environmental inputs									
SOM reduction	J	9.36E+04	Brandt-Williams, 2002	6.52E+15	22.98	1.16E+16	24.33	1.16E+16	18.59
Soil erosion	g	1.27E+09	Odum 1996	7.62E+14	2.69	7.62E+14	1.60	7.62E+14	1.23
Irrigation	J	1.92E+05	Campbell (man.)	1.60E+15	5.64	1.33E+16	27.93	1.33E+16	21.35
				8.88E+15	**31.31**	**2.56E+16**	**53.86**	**2.56E+16**	**41.16**
Purchased inputs									
Human labour	J	2.22E+06	Lu et al., 2009	4.19E+15	14.77	2.58E+15	5.44	2.09E+15	3.37
Machinery	g	1.01E+10	Campbell et al., 2005	1.35E+13	0.05	4.63E+13	0.10	1.55E+14	0.25
Fossil fuel and lubricants	J	8.60E+04	Bastianoni et al., 2009	5.14E+14	1.81	1.16E+15	2.45	1.42E+15	2.29
Nitrogen fertilizer	g	3.09E+10	Brandt-Williams, 2002	2.56E+15	9.02	4.267E+15	8.98	5.69E+15	9.15
Phosphorus fertilizer	g	2.82E+10	Brandt-Williams, 2002	2.30E+15	8.10	2.59E+15	5.46	2.27E+15	3.65
Potash fertilizer	g	2.23E+09	Odum, 1996	1.59E+14	0.56	1.67E+14	0.35	1.675E+14	0.27
Boron fertilizer	g	3.91E+09	Lan et al., 2002	-	-	-	-	4.10E+14	0.66
Micro fertilizer	g	2.96E+08	Odum, 1996	1.56E+13	0.06	3.13E+13	0.07	3.13E+14	0.5
Organic fertilizer	g	1.89E+10	Hu et al., 2010	5.92E+15	20.88	5.92E+15	12.47	1.78E+16	28.58
Pesticide	g	1.89E+10	Hu et al., 2010	2.38E+13	0.08	6.65E+13	0.14	6.65E+13	0.11
Herbicide	g	2.31E+05	This work	3.80E+13	0.13	7.60E+13	0.16	1.33E+14	0.21
Electricity	J			1.66E+15	5.87	2.66E+15	5.60	2.83E+15	4.55
Installation of irrigation system	Rials	2.50E+08	Amiri et al. (2019)	-	-	7.50E+14	1.58	1.75E+15	2.82
Seed	Rials	2.50E+08	Amiri et al. (2019)	1.20E+15	4.23	6.00E+14	1.26	6.00E+14	0.97
				1.86E+16	**65.56**	**2.09E+16**	**44.06**	**3.57E+16**	**57.38**
				2.84E+16		**4.57E+16**		**6.21E+16**	
Output									
Root yield	sej g^{-1}			5.06E+08		5.28E+08		6.65E+08	
Root yield	sej J^{-1}			3.11E+04		3.24E+04		3.47E+04	

3.1.3. Purchased renewable and non-renewable resources

Input and output data for different production systems are presented in Table 4. The shares of purchased resources from traditional, semi-mechanized, and mechanized cultivation of total input emergy were 65.56, 44.06 and 57.38%, respectively. In traditional cultivation, 39.88% of total emergy input belonged to purchased renewable resources (manpower, livestock manure and seed) and 25.68% of total emergy input was purchased non-renewable resources (fertilizers, pesticides, and establishment costs). The shares of purchased renewable and non-renewable resources in semi-mechanized cultivation were 19.17% and 24.89% of total emergy of purchased resources, respectively, and in mechanized cultivation, 29.98% and 27.48% of total emergy of purchased resources were purchased renewable and non-renewable resources (Figure. 3). An increase in the share of purchased resources in mechanized cultivation compared to semi-mechanized cultivation was due to the high consumption of animal manure in this planting system. Based on the results presented in Figure. 3 and Tables 2 and 3, the highest amounts of emergy form purchased non-renewable resources in traditional, semi-mechanized, and mechanized manure application were 5.92E+15, 5.92E+15, and 1.78E+15 sej (20.88%, 12.47%, and 28.58% of total input emergies, respectively). After livestock manure, in traditional cultivation, manpower (14.77%) and in semi-mechanized and mechanized nitrogen fertilizer the highest shares of purchased emergy resources were 8.98 and 9.15%, respectively. In traditional farming, the higher share of livestock manure is because most farmers in this type of farming system are also engaged in the cultivation of cattle and sheep and use the manure produced at their farms at the end of each year. In mechanized crops, because of their greater financial capacity, they buy and use these fertilizers in their planting systems. In sugar beet cultivation, the high nitrogen requirement and the farmers' tendency to use chemical fertilizers to increase economic yield (root yield) have increased the share of chemical fertilizers, and the use of manpower in controlling weeds and other operations, such as irrigation and harvesting, has increased the share of labor power.

3.2. Yield and emergy output

The economic yields of sugar beet in traditional, semi-mechanized, and mechanized cultivation were 56, 90, and 100 Mg ha^{-1}, respectively (Table4).Mechanized cultivation consumed 33.33% and 109% more total emergy than semi-mechanized and traditional farming, respectively. The main reason for the difference in the amount of output emergy in different planting systems is the amount and type of resources in each planting system. Greater use of inputs, especially purchased inputs in the mechanized planting system, results in a higher amount of emergy in this cultivation method. Asgharipour et al. (2019) reported the highest and lowest total emergy in the high input system and ecological cultivation of beans, compared to different planting systems. It is believed that the higher total emergy in a system, shows that the system is utilizing existing resources and has a high degree of industrialization (Lu et al., 2010). Asgharipour et al. (2019) believe that planting systems that have high amounts of environmental or purchased input also have higher total emergy.

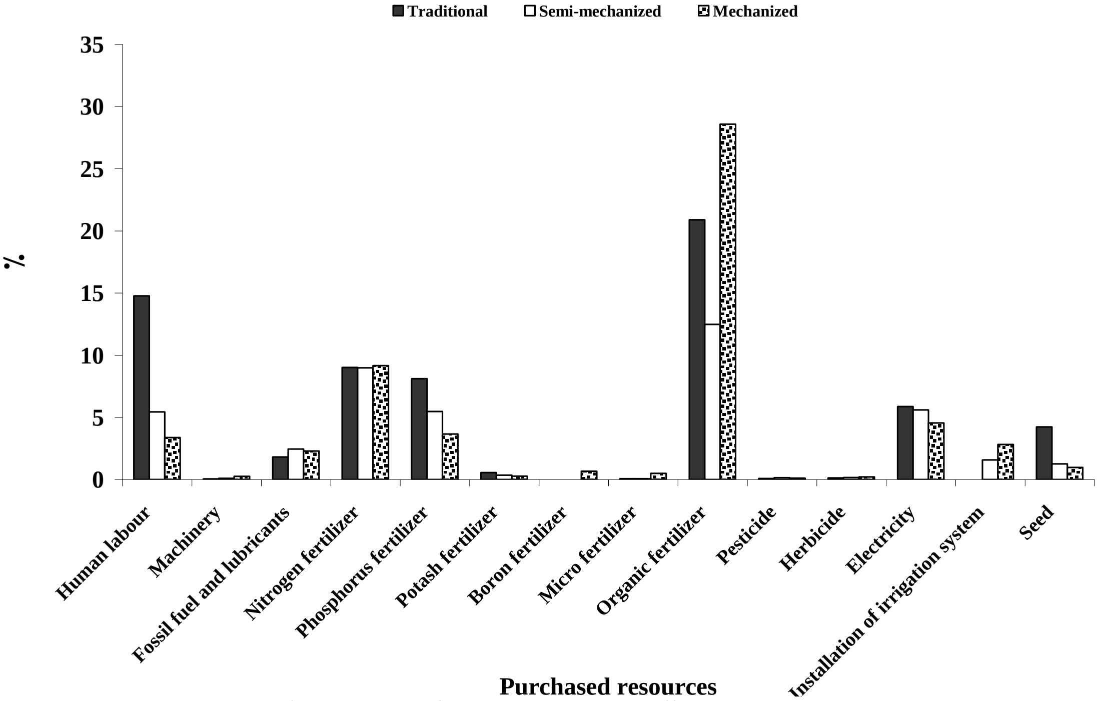

Figure 3. Structure of emergy inputs for purchased input at different sugar beet production systems

3.3. Emergy-based indices of production systems

3.3.1. Unit emergy value

The unit emergy value obtained by dividing the total input emergy by root yield (kgha^{-1}) for traditional, semi-mechanized, and mechanized cultivation was 3.11E+04, 3.24E+4 and 13.47E+04sejJ^{-1}, respectively (Table 5). The reason for the higher unit emergy value for mechanized cultivation, despite the higher yield, is the higher emergy consumption in this production system. Moonilall et al. (2020) reported that non-use of fertilizers significantly decreased yield but increased unit emergy value compared to fertilizer application. Consumption of Chemical fertilizer, Poultry manure biochar, Rice hull biochar and Sugarcane filter press compared to non-fertilizer treatment reduced yield by 779, 744, 715 and 658%, respectively, and reduced unit emergy value by 88.2%, 71.58%, 73.78% and 85.88%.

3.3.2. Renewable emergy ratio (R%)

Renewable emergy ratio (R%) representing the shares of renewable environmental resources and those purchased from all the production sources, was calculated by dividing the renewable emergy input resources by the total emergy, which was the highest and lowest for the traditional (43.01%) and semi-mechanized (21.24%) cultivations, respectively (Table 5). The higher R value indicates more reliance on a system on renewable resources and good sustainability, while its lower value represents its low renewability and poor sustainability. The higher R value in traditional cultivation was due to the lower system resources purchased. Its higher value in the mechanized compared to the semi-mechanized cropping system was because of its more frequent manure fertilizer application.

Table 5. Emergy indices for Sugar beet in different production systems

	Traditional	Semi-mechanized	Mechanized
UEV	3.11E+04	3.24E+04	3.47E+04
R (%)	43.01	21.24	34.38
EER	100	155	177
EYR	1.53	2.27	1.74
EIR	0.67	1.27	0.75
ELR	2.28	1.79	2.31
ESI	1.90	0.79	1.35

It should be noted that 24% of the total emergy in the mechanized cultivation was devoted to manure fertilizer, while only 11% of the total emergy in semi-the mechanized cultivation was made up of animal manure. It is believed that in crop systems with higher shares of renewable resources than total emergy, R value is also higher. In contrast, crop systems with purchased resources have a higher share of total emergy and a lower R value (Moonilall et al., 2020). It has been reported that proper management of field operations with the use of biological fertilizers can improve soil quality and reduce the amount of non-renewable emergy input to the production system. Under such conditions, the amount of soil erosion and decomposition, as well as the number of chemical fertilizers, decrease, and water storage capacity and carbon storage increase(Lal, 2018). These changes make the production system less dependent on purchased non-renewable resources and allow more use of renewable or purchased environmental resources (Moonilall et al., 2020).

3.3.3. Emergy exchange ratio(EER)

The emergy exchange ratio (EER), which is derived from economic yield into total emergy, reflects the amount of economic income per system in exchange for consumed emergy and, as a bridge, links economic analysis to emergy analysis.This indicator shows the relationship between the amount of purchased emergy received from the output of a product when sold in the market (Amiri et al., 2019). In our study, as the level of mechanization increased, EER was seen to be promoted from a traditional to a mechanized system. Therefore, the mechanized cultivation had 11.67% and 83.34% higher EER values than those of the semi-mechanized and traditional systems, respectively. The higher root yield in the mechanized cultivation was the main reason for the higher EER values despite the higher total emergy content in this system.EERs were 0.94 and 0.31 in the commercial canola and subsistence cultivation systems, respectively (Amiri et al., 2019).

3.3.4. Emergy Yield Ratio (EYR)

This ratio, which demonstrates the ability of a production system to use the purchased resources, was obtained by dividing the emergy of the yield into the total emergy of the purchased resources (Agostinho et al., 2008). Although both the mechanized and semi-mechanized systems had higher EYR values than the traditional system, this ratio decreased by 13.58% in the mechanized compared to the semi-mechanized system (Table 5).The lower EYR in the traditional system was due to the higher percentage of resources purchased in this system as compared to the semi-mechanized and mechanized systems.It is believed that a high EYR value cannot be a measure of the high sustainability of a system's production. Exploiting a system of available free resources may not necessarily reflect its efficiency.In fact, compared to industrial systems, traditional farming systems have a good ability to exploit free resources. however, their production efficiency is usually low, which reduces EYR.Contrary to the above results, it was observed that EYR in subsistence canola cultivation was higher than that of commercial cultivation (Agostinho et al., 2008).

3.3.5. Emergy Input Ratio (EIR)

The EIR index is the ratio of the sum of the emergy of non-free inputs to the sum of free inputs. In other words, this indicator indicates the degree of dependence of an agricultural system on the environment and the level of economic development. In this study, there was an inverse relationship between the mechanization level and the EIR.EIR values in the traditional, semi-mechanized, and mechanized systems were 0.67, 1.27, and 0.75, respectively (Table 5). Moonilall et al. (2020) also argued that a higher EIR index would be obtained by using more purchased resources in a production system, whereas the highest EIR value could be observed by the lower values of no-fertilizer planting systems as well as in planting systems that make use of chemicals or bio-fertilizers. These findings are consistent with the results of this research.

3.3.6. Environmental Loading Ratio (ELR)

This index is derived from the division of purchased and non-renewable environmental resources into renewable environmental resources and shows the amount of pressure and stress imposed on the environment by a cropping system. Higher values of this index reflect more enormous environmental pressure on local ecosystems due to the use of non-renewable resources (Odum et al., 2000). ELR values of <2, 2-10, and >10 correspond to low, moderate –to –high, and intense pressures on the environment imposed by a production system, respectively (Agostinho et al., 2008). In this study, the semi-mechanized systems had lower ELR values than 2, and the traditional (2.28) and mechanized (2.23) systems had higher ELR values than 2(Table 5). It has been reported that commercial cultivation has a higher ELR value than subsistence cultivation (Amiri et al., 2019). ELR values of less than 2 have been shown in different maize cultivation systems (Moonilall et al., 2020).

3.3.7. Environmental Sustainability Index (ESI)

The ESI is a composite index obtained by dividing the EYR index by ELR (Amiri et al., 2019). It measures the benefits of a system per unit area. In other words, this indicator measures a system's advantage over its costs. Therefore, ESI takes into account both the economy and the environment. Higher values of this index indicate greater stability of a system under study (Brown and Ulgiati, 2004).According to the research conducted by Brown and Ulgiati (2004) ESI values of >10,1-10, and <1 represent stable systems of low pressure, systems of good potential, and a high-power system with high environmental impacts that deplete system resources and require high emergy consumption to survive, respectively. The higher the share of renewables than non-renewables, the higher the index value and the more favorable the system will be. This indicator can help identify agronomic ecosystems that are less environmentally friendly and more dependent on local renewable resources for production.

In this research, semi-mechanized and traditional cultivation had the lowest (0.79) and highest (1.90) values of ESI, respectively. The values of this index in the two mechanized and traditional systems were slightly different. A production system with a high EYR and low ELR will always have higher ESI values, suggesting that it is more environmentally friendly, has fewer environmental impacts, and is thus more sustainable. Contrary to the above results, the highest ESI value was observed in maize without using fertilizer and chemical applications and the lowest ESI value was observed with biochar use (Moonilall et al., 2020). In the environmental assessments of different sugar beet cultivation systems, Bazrgar (2011) reported that the mechanized cultivation had fewer negative environmental impacts than semi-mechanized and traditional systems. The environmental superiority of the mechanized compared to the traditional systems was mainly due to their higher production, lower input consumption, and lower environmental emissions per tonne of sugar beet production. In terms of global warming potential, marsh potential, acidification potential, demand for non-renewable energy, ozone depletion potential, and land use, the mechanized fields revealed less-than-the-mean effects of environmental damage during the production process of one tonne of sugar beet. In their study, Ortega et al. (2005) reported that the biological (ecological and more biocompatible organic) approach provided more sustainability than the industrial (agrochemical and no-till using herbicide) approach in soybean cultivation.

3.4. Relationship between yield and sustainability

Among the studied systems, mechanized cultivation had the highest root yield and highest sustainability. Nonetheless, despite increased root yield, production sustainability decreased in semi-mechanized cultivation compared to traditional cultivation. It seemed that the main reasons for the higher production sustainability in the mechanized cultivation were the higher share of purchased inputs, increased efficiency of using inputs, and a higher share of purchased renewable resources, especially livestock manure. The results of this study are in line with the findings of Bazrgar (2011), who maintained that the mechanized cultivation of sugar beet had less environmental impact compared to traditional cultivation. Contrary to the above results, Moonilall et al. (2020) reported that the highest sustainability of maize production occurred in the non-chemical fertilizer treatment, while chemical or biochar applications increased the yield, but decreased sustainability. Ren et al. (2019) reported that by increasing farm size, significantly decreased fertilizers and pesticides could be consumed per hectare, which demonstrates the obvious benefits of protecting the environment.

5. Conclusion

Each of the three studied systems had different effects on the shares of the varied sources of total emergy. The traditional and mechanized cultivations required the least and the highest amounts of emergy for crop production, respectively. The mechanized cultivation had 119% and 36% more total emergy compared to the traditional and semi-mechanized cultivations, respectively. Except for the share of manpower in the traditional cultivation, which was higher than those of the semi-mechanized and mechanized cultivations, the other resources purchased in the traditional cultivation declined sharply as compared to the mechanized cultivation. The mechanized compared to the traditional crop production needed less manpower (50%) and 100% seed, but more machinery (1148%), fuel and oil (276%), nitrogen fertilizer (22%), phosphorus fertilizer (99%) ,potassium fertilizer (105%), manure (301%), insecticides (279%), herbicides (350%), and electricity (70%). The semi-mechanized cultivation was also more similar to the mechanized cultivation in most of the sources purchased compared to the traditional cultivation. The ELR index, as an indicator of production stability, was higher in traditional cultivation, but the mechanization of sugar beet cultivation did not significantly decrease this index. Since economic yield was higher in the mechanized cultivation, other emergy indices, except for renewable emergy ratio, were higher in the mechanized compared tothe traditional cultivation. Based on this result, it could be said that the mechanization of sugar beet cultivation in the study area had improved the yield while also maintaining the system stability.

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