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A Sustainability Analysis of Two Rapeseed Farming Ecosystems in Khorramabad, Iran Based on Emergy and Economic Analyses

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Abstract

In the past two decades, rapeseed farming has garnered attention, because it offers the possibility of attaining self-sufficiency in the production of edible oil, which is a strategic product for Iran. Therefore, the overarching goal of this research was to provide sound strategies to further the development of rapeseed farming and to increase the sustainability and productivity of rapeseed production systems. Progress toward this goal was made by assessing subsistence and commercial rapeseed production systems in Khorramabad, Iran during the 2017–2018 crop year using both emergy and economic indices. The calculated values of the ESI*, %R, ELR, and ELR* indices showed the higher ecological sustainability of the subsistence farming system compared to the commercial system of rapeseed production. According to these indices, the main reason for the lower sustainability of the commercial rapeseed production system was the large amount of soil organic matter that was lost per unit input of nonrenewable resources used. A large emergy exchange ratio in favor of the buyer, the increased environmental sustainability when the market impact is considered, the lower emergy consumption per unit of output, and the higher productivity of the production factors all reflect the relative advantage of the commercial system based on the indices of EER_Y, EISD, UEV, and total factor productivity (TFP), respectively. Hence, our findings revealed that in the commercial rapeseed production system, the ecologic sustainability of the system can be improved drastically by employing scientific solutions for the comprehensive management of the production ecosystems, especially through the amelioration of soil organic matter and prevention of its loss. Besides improving the farmers' technical knowledge, the integration of small lots into the production system is recommended for improving the economic sustainability of the subsistence production system.

Keywords

Rapeseed cropping systems; Commercial production; Subsistence production; Emergy Synthesis; Economic Input-Output Analysis

1. Introduction

Farming is among the activities that result in the highest level of human influence on ecosystems (Steffen et al., 2015; Rockstrom et al., 2009, 2016). Due to the necessity of securing adequate access to food, changes have been made to farming methods, which has increased interest in industrial farming (often in large-scale production) and will result in qualitative changes in the ecosystem and quality of life of the residents of the farming regions (Toledo, 2003). Moreover, sustainability is known as the key to guarantee the social, cultural, and economic life of crop production systems. The preservation and establishment of sustainability also calls for the right comprehensive assessment and analysis techniques (Quintero-Angel and Gonzalez-Acevedo, 2018). In this regard, holistic sustainability assessment approaches, which cover the ecologic, economic, and social dimensions of the system, reveal useful information on the current condition of interventions in agricultural ecosystems (Perez, 2007).

One solution to insure agricultural development and sustainability is to accurately value the interaction between energy and the environment. To accomplish this, one novel method of sustainability analysis that is based on qualitative and quantitative estimates of available energy, or energy with the potential to do work is emergy analysis (Odum, 1996, 2007). A group of scientists have long thought of emergy as the bridge connecting the environment to economics (Odum, 1996; Ulgiati et al., 1993; Brown and Ulgiati, 1997; Copeland et al., 2010; Lan et al., 1998, 2002). Emergy analysis has also performed successfully in the analysis of farming systems and farms (Giannetti et al., 2011; Lu et al., 2010; Zhang et al., 2011 and 2012). Energy Systems Theory (Odum 1983, 1994) forms the theoretical and conceptual basis for the emergy methodology (Odum, 1996). In fact, emergy is the available solar energy or exergy utilized directly or indirectly for the production of commodities, services, or products. Emergy is also known as the embodied energy or the “energy memory” and is quantified in terms of solar emjoules, abbreviated as sej (Odum et al., 2000). By calculating all flows, natural reserves, and economic sources and converting them into solar emjoules for the calculation of appropriate indices, an emergy analysis can serve as a comprehensive sustainability analysis.

Valuable studies have been carried out on the sustainability of farming systems at different scales based on both emergy and economic indices. For example, Asadollahpour et al. (2016) studied the economies of scale and the production structure of rapeseed in Iran and indicated that the structural properties of farming this product (e.g. farm size and production methods) have been the cause of an ascending trend in the efficiency of rapeseed production in Iran. In other words, with an increase in farm size, the production costs decrease. Hence, larger farms have a relative advantage over smaller farms in terms of costs and efficiency, and adoption of an efficient policy for rapeseed farms can result from scaling-up production and thereby reducing expenses. Some researchers also argue that small land areas under subsistence cultivation are more efficient than large land areas, attributing this relative advantage to the activity of the family members on small farms (Danesh-Shahraki et al., 2008). On the other hand, there are experts that are concerned by small-sized farms, because they believe small farms disrupt the utilization of the lands and other production factors, while rapid technological changes and growth of commercial farming cause a shift from small farms to larger farms of higher productivity. They argue that the use of chemical fertilizers and new species of improved seeds in modern agricultural methods is more effective and important than the local workforce for attaining higher production volumes and greater sustainability of production (Thapa, 2007; Yazdani and Shahbazi, 2009). The use of new technologies, such as the increase of mechanization in large farms, can cause large losses of organic matter from the soil and, eventually, reduce the sustainability of the system (USDA, 2003 and 1996). In addition, the results from the emergy analysis of wheat and corn production systems in the northern plains of China by Wang et al. (2014) revealed that the efficiency of corn production on large-scale farms was 64.7–88.5% higher than on ordinary production systems, while the emergy efficiency of the production of wheat on the same farms was 23.5% lower than that on the other wheat production systems.

More than 90% of the local demand for edible oils in Iran is met by imported raw or processed oils. As a result, the import of oilseeds and oils accounts for a large fraction of the country’s currency exchange (Danesh-Shahrakiet al., 2008), and thus long-term integrated planning aimed at self-sufficiency of edible oil production is a must to attain food security for the nation. In this regard, the cultivation of rapeseed has gained attention due to the unique properties of this product, such as its improved performance compared to other crops cultivated adjacent to it, its compatibility with the weather of Iran, its high oil content, which is more than 25 to 55% by weight, (Wu et al., 2008), and its high nutritional quality (Zomorodian et al., 2011). In fact, this crop is considered to be the best hope for attaining a sustainable supply of edible oils for Iran in the future. Research on rapeseed cultivation in Iran was begun in 1998 and essentially, rapeseed was not cultivated in Iran before the last two decades.. The “rapeseed production and development plan” was launched in 1999 and the area of this plant under cultivation has grown in recent years all over the country. Moreover, in the past two decades, subsistence production of rapeseed has been practiced in Iran, especially in the study area (Mirhashemi and Banayan Aval., 2012).

The global production of rapeseed in the 2017 crop year (the beginning of the rapeseed crop year in the study area) was approximately 72.7 million tons (FAO, 2017). The cultivation area of rapeseed in the 2017–2018 crop year (the study year) in Iran was 103,044 ha and production was 185,000 metric tons. The area under cultivation in Lorestan Province and Khorramabad City was 2360 ha and 467 ha, respectively. The average yield in Khorramabad was 2008 kg ha^{-1}. To increase the area of rapeseed under cultivation, an approach revolving around the development and promotion of the cultivation of this product and its systemic relationships was used to inform farmers and to set the stage for the acceptance of this innovation. This approach involves information transfer by subject-matter experts and their aid in developing plans for proposing various solutions for gaining relative advantage in the market and for increasing rapeseed production capacity (Sedigi, 2001). Despite the measures mentioned above, the current rate of development of rapeseed cultivation is not acceptable, and there is still a lack of a suitable paradigm for production methods that describes an optimum size for rapeseed agricultural ecosystems, which has hindered its development and sustainability in Iran. Hence, finding the relationship of the production method (commercial or industrial) applied within the rapeseed ecosystems that results in sustainable production and high productivity will serve as a valuable solution for gaining relative advantage in producing and stabilizing the production of rapeseed. Planners in the agriculture sector have introduced the dispersion and small size of farmlands as two of the major barriers to furthering the sustainability of crops and commercial production of crops in Iran (Yazdani and Shahbazi, 2009). In addition, in the past decades, due to the increased public environmental awareness and the demand for environment-friendly production methods, agricultural scientists have been paying more attention to cleaner production and have introduced environmental protection as the basis for further development and increased sustainability of rapeseed and other crops (Khoshnevisan et al., 2015).

The necessity of food security, the increasing shortage of the resources and inputs needed to support the agriculture sector, and the serious threat posed by agricultural ecosystems to the environment double the need for comprehensive sustainability analyses of farming systems and the development of an information base that allows for wise decisions and thereby better management of farming systems. The overall goal of agriculture is to secure sustainable production from farming systems by supplying nutrients and diminishing negative environmental impacts. To this end, a precise image of the sustainability of two rapeseed production systems in Khorramabad (Iran) can be projected by assessing and comparing the subsistence and commercial rapeseed production systems through the integration of emergy and economic indices. Afterwards, based on the results from these analyses, solutions for the development of the cultivation and stabilization of rapeseed production and the optimum inclusion of this plant in the cultivation model of the region will be proposed.

2. Materials and methods

2.1 Sites in the study area

This research was carried out on the subsistence and commercial systems for rapeseed production in the west of Khorramabad City, the capital of Lorestan Province, at an altitude of 1155m in the Zagros valleys. The long-term average annual precipitation and average annual evaporation in the region are 496.7 mm and 1835.0 mm, respectively. The maximum and minimum absolute temperatures recorded in Khorramabad are 47 and −14.6°, respectively. The average precipitation in the study region and crop year (September 23, 2017- June 21, 2018) was 488mm, while the maximum and minimum average temperatures within this period were 22 and 6.6°*C*, respectively. In general, this region has a sub-humid climate with hot summers and relatively cold winters (Lorestan Province Statistical Yearbook, 2016). The soil on both sites is of the inceptisol soil order with clear calcium cambic and agric horizons. The soil in the study area has a moderate to heavy texture, an acidity of 7.5 to 8.1, and salinity of below 4 dS m^{-1}. These soils are classified as calcareous soils, because they contain considerable amounts of lime in their surface and subsurface horizons. The commercial rapeseed production system covers a populated area of 80ha in Chogahoroosh village at 33.3808N and 48.1415E, while the subsistence rapeseed production system covers a one-hectare area in Papikhaldar village at 33.3246N and 48.1920E. These two villages are situated at the center of Khorramabad and are accessed via two separate rural roads 10 km from Khorramabad City.

The rapeseed cultivars in the commercial site were Hydromel, Xpower, and Natalie and the Hyola401 cultivar was cultivated on the subsistence site. The machinery used for plowing and preparing the seedbed and harvesting rapeseed included the Ferguson 399 (110Hp) and

Ferguson 475 (75Hp) tractors, the necessary trailers, and New Holland 5070 (206ha) and John Deere 1165 (160Hp) combine harvesters. Nitrogen, phosphorous, potassium, and sulfur fertilizers were also used in the form of urea, triple super phosphate plus ammonium phosphate, potassium, and ammonium sulfate, respectively. In the commercial site, a micronutrient, Greenelyte solution, was used for absorption by leaves in addition to the typical fertilizers. In both systems, premium quality toxins were used as pesticides, whereas in the commercial system Gallant Super and Lontrel herbicides were used. Irrigation water with electrical conductivity of 0.37 and 0.28 dS m^{-1} was provided to the commercial and subsistence sites, respectively. The commercial and subsistence sites were also irrigated using pressurized irrigation (sprinkler irrigation) and conventional irrigation (flood irrigation) techniques and a river supplied irrigation water to both sites.

2.2 Data collection

In this research, in order to calculate the emergy indices and carry out an economic analysis in the commercial and subsistence rapeseed farming ecosystems; first the free renewable and nonrenewable environmental inputs, as well as the commercial inputs, were identified for each ecosystem and then measured or estimated in the 2017–2018 crop year. The free renewable environmental inputs included sunlight, rain, wind, evapotranspiration, and river water. The free nonrenewable environmental inputs included soil erosion and organic matter loss. The commercial inputs were chemical fertilizers, pesticides, herbicides, machinery, fuel, organic fertilizers, workforce labor, and electricity, which were outsourced. Finally, the outputs of the two ecosystems were rapeseed and wheat straw.

2.3 Emergy analysis approach

Numerous researchers have presented the details of emergy calculation (Uligati et al., 1994; Odum, 1996; Brown and Ulgiati, 1997; Campbell, 1998; Odum et al., 2000). The first step in emergy analysis is identifying the temporal and spatial boundaries of the two study ecosystems and drawing the Energy Systems Language (ESL) diagram of the systems to be evaluated for classification of the inputs to the study systems into renewable and nonrenewable categories, as well as, distinguishing local and imported resource groups. This is necessary for management of the relationships between the main components and the profitable system processes and displays the environmental pillars of these ecosystems and their interconnections. Figures (1) and (2) present the Energy Systems Language diagrams for the two rapeseed production systems examined in this paper. Besides, ESL models “speak” in a symbolic mathematical language in modeling processes, and this language depicts the systems network properties (Odum, 1996). The second step in emergy analysis is the preparation of the emergy assessment tables as described in Campbell and Ohrt (2009), for example.

In the analysis of production systems, resources can be classified into four categories (Ortega et al., 2002): 1) renewable environmental resources (R), which include sunlight, wind, rain, river water, and evapotranspiration; 2) renewable environmental inputs used in a nonrenewable way (N_0), which include erosion and soil organic matter loss. The soil organic matter losses and soil erosion are from different strata. The estimation of soil losses through erosion was carried out by estimating the displacement of the soil surface in the field based on the Universal Soil Loss Equation (USLE) technique. These losses are generally related to surface soils. The amount of energy from these losses was measured by the loss of mineral matter. However, losses of soil organic matter were measured by taking soil samples from pre-sowing and after harvesting crops at a depth of 30 cm. This decrease is mainly due to the biological and microbial activity in the soil and the loss of organic carbon in the form of CO_2 emission to the atmosphere. In the commercial system, the organic losses of the soil were greater due mainly to different tillage operations, the use of more nitrogen fertilizer and the intensification of biological and chemical interactions lead to greater consumption and organic carbon decomposition, preventing the growth of weeds in the field, which are a source of soil organic matter. 3) purchased renewable resources (FR), which in this case include 80% of organic fertilizers, 43% of the seed, 10% workforce labor, and 1% of electricity; and 4) purchased nonrenewable resources (FN), which include farming machinery, fossil fuels, fertilizers, and chemical toxins including 99% of electricity, 90% of the workforce labor, 57% of the seeds, and 20% of nonrenewable organic fertilizers (Asgharipour et al., 2019). The irrigation water for both sites was classified as a renewable input, because the water was supplied from a river. Rapeseed was cultivated on both sites in autumn. The emergy of both water resources (rainwater and river water) was calculated based on the distribution and comparisons of precipitation in the growing season and the partial satisfaction of the rapeseed water demand obtained using precipitation.

The average erosion in the commercial and subsistence systems was 1.42E+6 and 3.21E+6 g ha^{-1}, respectively (Vaezi et al., 2008; Ostovari et al., 2016). However, the variations of the energy reserves due to the loss or growth of soil organic matter are rarely taken into account in energy analyses, despite the substantial importance of these reserves (Fan et al., 2018). In this study, the loss of soil organic matter was calculated by assuming that loss exceeds the rate of replacement and thus it is an energy input to the rapeseed production system. The emergy of machinery was approximated based on the weight of steel (its major material component), the economic lifetime of the machinery, and the machinery operating hours per year (Campbell et al., 2005). The emergy flow per currency unit[1] was used to estimate the emergy of the seeds and the pressurized irrigation system (Asgharipour et al., 2019). The energy contents of the rapeseed and wheat straw products were calculated by burning them in a calorimeter (Parr-6200 calorimeter).

After calculating all inputs (U) and outputs (Y) flows, the data on the flows of each production system were multiplied by the appropriate transformities in terms of sej per joule, gram, or dollar (Lu et al., 2009; Bastianoni et al., 2009; Campbell et al., 2005; Odum et al., 2000). The transformities for electricity and money were selected based on research by Asgharipour et al. (2019) given the conditions in Iran.

Emergy analysis relies on indices resulting from the environmental and economic analyses as discussed in Lu et al., (2010, 2018). In this research, the unit emergy value (UEV), renewable emergy ratio (%R), emergy investment ratio (EIR), modified EIR (EIR*), emergy yield ratio (EYR), environmental loading ratio (ELR), modified ELR (ELR*), environmental sustainability index (ESI), modified ESI (ESI*), emergy exchange $ratio_{Yield}$ (EER_Y), and

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[1] 2.50E+08 sej Iranian $Rials^{-1}$

Emergy Index for Sustainable Development (EISD) were used to compare the rapeseed commercial and subsistence ecosystems. The specifications and formulae for the emergy indices used in this research are presented in Table 1.

2.4 Economic analysis

All countries are pursuing advances in sustainability by attempting to reduce the consumption of resources and at the same time increase production. To accomplish this Evenson et al. (1999) suggest that the developing countries must rethink their agricultural sectors and integrate them with advanced technologies to modernize this sector and increase productivity. An important economic tool for assessing the performance of farming systems and making productivity measurements is an evaluation of total factor productivity (TFP) (Lynam and Herdt, 1989). TFP is defined as the total economic value of all system outputs produced during one production cycle of the system divided by the total economic value of all inputs required over the same time period. TFP is actually an improvement in measuring the quality aspect of inputs and reflects the efficiency and effectiveness of the combined use of production factors, and in addition, it can be used to indicate the optimal use of system inputs. This indicator allows a more intelligent use of available resources, the updating of existing technology and the use of new technologies, better management techniques, specialization, efficiency improvement, training and skills development in the active workforce (Kiani, 2008). By calculating and analyzing the total factor productivity (TFP) index, it is possible to analyze the productivity of the resources used in different economic sectors. A nonnegative trend in TFP over the period of an evaluation indicates that the system is sustainable over this time. In this research, this index was analyzed using the data collected from both commercial and subsistence rapeseed production systems and the prices of inputs in the Iranian market during the research year.

3. Results

3.1 Structure of Emergy use in rapeseed production

The physical units of free and purchased environmental inputs to the commercial and subsistence rapeseed production systems are listed in Table 2. All of the inputs listed in this table were converted into emergy flows after being multiplied by the appropriate transformities derived from previous research, after analyzing their applicability to the present emergy evaluation (Table 3).

The estimated total emergy input of the commercial and subsistence rapeseed production systems in this research was 4.13E+16 and 2.47E+16 sej ha^{-1}. The comparison of these two figures reveals that the total emergy input to the commercial system is approximately 67% higher than that applied to the subsistence rapeseed production system. In general, a larger emergy input to a system is linked to the degree of mechanization and industrialization of that system (Lu et al., 2010).

3.1.1 Renewable environmental flows—Renewable environmental flows include sunlight, wind, rain, evapotranspiration, and river water (Tables 2 and 3). Wind, rain, evapotranspiration and flowing water directly originate from solar energies. Hence, to avoid repeated counting of inputs, the largest source of the renewable planetary flows (wind and rain) plus solar energy, which is used in photosynthesis, were considered to form the emergy of renewable environmental flows (Asgharipour et al., 2019). The free renewable energies used in the commercial and subsistence systems equaled 1.99E+15 and 1.80E+15 sej ha^{-1}, respectively. Implementing some crop improvement requirements in the commercial system, such as planting on the proper cultivation date and the use of cultivars with longer growing periods increased the growing period of rapeseed by 38 days and consequently the free environmental energies input to this system as compared to the subsistence ecosystem. This source accounted for 4.81% and 7.31% of the total emergy input to the commercial and subsistence systems, respectively.

3.1.2 Nonrenewable environmental flows that is potentially renewable—Two nonrenewable environmental sources of emergy are soil erosion and soil organic matter loss (Tables 2 and 3). Nonrenewable environmental flows account for 51.71% and 27.35% of the total emergy flowing into the commercial and subsistence systems, respectively. The largest share of nonrenewable environmental flows in the commercial system was soil organic matter loss; and in the subsistence system, it was soil erosion. In the commercial system, soil organic matter loss makes up 47.34% of the total input (1.96E+16 sej ha^{-1}), and the measurement of soil organic matter loss is an important step in energy analysis (Fan et al., 2018). According to the measurements by Lu et al. (2009), the calculated organic matter decay in the guava, wampee, and papaya production systems in China was 1.32E+16, 8.93E+15, and 6.51E+15 sej ha^{-1} which accounted for 21.36%, 20%, and 11.2% of the total emergy input to these systems, respectively.

The balance between the organic matter input and organic matter loss, which is provided by soil degradation and erosion, determines the amount of the soil organic matter. Preservation of soil organic matter is difficult and its concentration grows very slowly, because almost 75% of the organic matter added to the soil is used to provide energy to the soil microorganisms and it leaves the soil in the form of carbon dioxide. The remaining amount is also insignificant and remains in the soil for a while in the form of organic matter (Haynes and Naidu, 1998). Hence, soil organic matter is considered a nonrenewable resource.

In the course of rapeseed production in the commercial and subsistence systems, organic matter decay was 0.22 and 0.03% as compared to the respective pre-cultivation levels. The higher organic matter loss in the commercial system as compared to the subsistence system was caused by several factors that were directly or indirectly linked to the different production approach adopted in the commercial system. The use of cultivars with a high harvest index, monocropping, use of chemical herbicides, a very small population of weeds (which are a source of organic matter), removal of crop remains, and use of conventional tillage operations, all of which are pillars of the commercial farming systems, have resulted in the loss of organic matter. In addition, the excessive use of nitrogen chemical fertilizers in the commercial system has intensified the activity of microbes and that has accelerated soil organic matter degradation (USDA, 2003 and 1996).

3.1.3 Purchased input flows—The amounts of purchased inputs in the commercial and subsistence systems were 1.80E+16 and 1.61E+16 sej ha^{-1}. A comparison of the purchased resources for both systems reveals that despite the small difference in the total purchased emergy input of the two systems, there was a large structural difference between the two sets of inputs. For instance, the emergy of the workforce input to the subsistence system was about twice that of the commercial system. On one hand, the organic fertilizer input was 3.55E+15 and 0 sej ha^{-1} in the subsistence and commercial systems, respectively. On the other hand, the total of herbicide, electricity, and irrigation emergy deployed in the commercial system was 2.08E+15 sej ha^{-1} and it was zero in the subsistence system. Moreover, the emergy of farm machinery and fossil fuels used in the commercial system were, respectively, approximately 3 and 6 times that of their use in the subsistence system. The emergy of potassium chemical fertilizer used in the commercial system was approximately 3 times that of the subsistence system. The higher consumption of potassium in the commercial system could be attributed to the farmers' awareness of the important role of this element in the metabolism of photosynthesis, the increased yield, and the increased resistance of rapeseed to biological and non-biological stresses at high potassium levels (Noorgholipoor et al., 2014). The considerable difference between the types of purchased resources originated from the difference in the management approaches and the type of decisions made in implementing the production processes. In other words, different production models caused structural differences in the purchased inputs of both systems.

In the commercial system, the purchased inputs made up 43.49% of total inputs, whereas in the subsistence system purchased resources had the highest share of the total inputs (65.34%). Purchased inputs were classified into renewable and nonrenewable categories. In the commercial system, 2.00E+14 sej ha^{-1} and 1.77E+16 sej ha^{-1} of the total purchased input emergy was supplied from renewable and nonrenewable resources, respectively. However, in the subsistence system, renewable and nonrenewable resources supplied 3.13E+15 sej ha^{-1} and 1.30E+16 sej ha^{-1} of the total purchased emergy input. The difference between the types and amounts of the purchased renewable and nonrenewable inputs in both systems indicated that the degree of dependence of the commercial system on purchased nonrenewable inputs, such as machinery, chemical fertilizers, toxins, fossil fuels, electricity, and new irrigation systems was higher than that of the subsistence system. Although the extent of renewability of purchased resources in the subsistence system was higher than that of the commercial system, the renewable inputs of nitrogen and phosphorus chemical fertilizers made-up the largest share of the purchased inputs of the subsistence system.

3.1.4 Emergy output and yield—The total emergy output of the commercial and subsistence systems is 4.13E+16 and 2.47E+16 sej ha^{-1}, respectively (Table 3). With the same amount of crop (as the output in terms of J or g), the system with a smaller input emergy (in terms of sej) is a more efficient production process. In other words, with the same input emergy, the system that produces more output is more productive (Odum 1996; Brown et al., 2000). Table 2 presents the energy of the rapeseed and wheat straw outputs in terms of mass (g) and energy (J). Finally, the ratio of the total input emergy of each system to the economic oilseed outputs and wheat straw outputs can be used to analyze the productivity of both systems (Table 3).

3.2 Emergy indices

The analyses using the emergy indices for the assessment of the functional differences between the commercial and subsistence rapeseed production systems examine the following aspects: ecologic sustainability, resource efficiency, environmental impacts, economic efficiency, and competitive advantage in the market. The comparison of the emergy indices of the two systems reveals the methods of management and application of the production methods in both systems. The values of the emergy indices are listed in Table 1.

3.2.1 Unit Emergy Value (UEV)—The Unit Emergy Value (UEV) is an effective measure of the crop production emergy required per unit of output (Brown and Ulgiati, 2004). With equal production, a higher UEV is indicative of lower economic and environmental effectiveness of the emergy used (Odum, 1996; Lu et al., 2010). The UEV for rapeseed production in the commercial and subsistence rapeseed production systems is 2.60E+05 and 8.02E+05 sej J^{-1}, respectively. In addition, the UEV for the production of wheat straw in the commercial and subsistence systems is 2.60E+05 and 7.97E+05 sej J^{-1}, respectively. The UEV for the subsistence system is 3.08 times that of the commercial system. Therefore, in the commercial system, the input energy efficiency is 208% higher than the subsistence system. The higher UEV of subsistence rapeseed production can be attributed to the high consumption of inputs such as the irrigation water, chemical fertilizers, organic fertilizers, and labor, along with the low production of this system, which together explain its reduced efficiency compared to the commercial system. Although the emergy consumption of the commercial production system is 1.7 times that of the subsistence system, its production is 5 times greater, thus it is more effective in the conversion of the input emergy into yield (Table 3). In Martin et al. (2006), the UEV of a multiple cropping subsistence system (over an area of 12ha) and a corn production system (over an area of 89ha) was 2.32E+05 and 9.30E+04 sej J^{-1}, respectively. Wang et al. (2014) reported a UEV of 1.63E+05 sej J^{-1} for large-scale wheat production farms in the north of China. However, the UEV of this product on subsistence Danish farms was 1.32E+05 sej J^{-1} (Ghaley and Porter, 2013). Moreover, Zhang et al. (2005) and Cavalett and Ortega (2009) reported UEVs of 8.37E+04 and 1.01E+05 for small soybean production systems in China and Brazil, respectively.

3.2.2 Renewable Emergy Ratio (%R)—The renewable emergy ratio (%R) expresses the renewability of emergy inputs as a percentage of the total input (Zhang and Long, 2010). In general, the production systems wherein a larger portion of the input emergy is supplied from renewable resources or the production processes themselves consume more renewable resources are more sustainable (La Rosa et al., 2008). As the consumption of nonrenewable energies in a system decreases with an increase in the use of renewable resources, the system performs better in economic competition over the long run, assuming that nonrenewable resources will become more scarce over time (Brown and Ulgiati, 2004; Lefroy and Rydberg, 2003).

The calculated renewable emergy ratio (%R) of the subsistence and commercial systems is 19.90% and 5.30%, respectively (Table 1). In this research, the calculated %R of the commercial rapeseed production system indicates that nonrenewable resources supply a large percentage of the emergy input to this system. The emergy input provided by renewable resources in the subsistence and commercial systems is 4.93E+15 and 2.19E+15 sej ha^{-1}, respectively. The comparison of these values shows that the renewable input of the subsistence system is about 125% more than the commercial system and the %R of the subsistence system is about 3.75 times that of the commercial system. Based on the %R calculation formula presented in Table 1, the lower %R used in the commercial rapeseed production system as compared to the subsistence system is caused by the larger emergy input supplied from renewable resources in the subsistence system. More importantly, it is caused by the large role of the renewable emergy inputs used in a nonrenewable manner in the commercial system (Table 3). Similar to most related studies, nitrogen and phosphorous chemical fertilizers compose a large share of the nonrenewable emergy inputs (Ghaley and Porter, 2013).

In their research, Zhang et al. (2012) reported a renewable emergy ratio (%R) of 27% for subsistence production of corn in China, which is a low %R for a subsistence production system. Cavalett and Ortega (2009) studied soybean production in Brazil, where 75% of farmers carried out commercial farming and 25% of the farms were managed traditionally. They reported an %R of 35.6%.

3.2.3 Emergy Exchange Ratio$_{\text{Yield}}$—Emergy Exchange Ratio$_{\text{Yield}}$ (EER$_{\text{Y}}$) is introduced as the bridge connecting emergy to economic analyses (Lan et al. 2002). Expressed per unit area in this study, EER$_{\text{Y}}$ analyzes the emergy balance resulting from the sale of the rapeseed crops on the market. EER$_{\text{Y}}$ quantifies the balance between the emergy that can be purchased by the money received for the economic output when it is exchanged on the market. It is designated by Y$_{\text{M}}$, i.e., the emjoules that can be purchased using the money received per unit area of production, which is compared to the total input emergy (U) of the system required to produce the output from 1 ha. The EER$_{\text{Y}}$ for the commercial and subsistence systems in this research was 0.94 and 0.31, respectively (Table 1). In other words, only 94% and 31% of the input emergy of the commercial and subsistence systems, respectively, was received by the producers as a result of the exchange rate for rapeseed on the market. However, in the research by Lu et al. (2017 and 2009), the EER$_{\text{Y}}$ values for the lotus, lotus-shrimp, lotus-fish, banana, papaya, wampee, and guava produced on farms in China were 2.6, 2.5, 4.2, 2.5, 1.8, 3.6, and 1.9, respectively. These EER$_{\text{Y}}$ values represent acceptable and high levels of EER$_{\text{Y}}$. In other words, when the purchasing power of money to buy emergy on the market is used to convert the physical output of these systems to emergy through the market exchange, the value received is at least 1.8 times more than the consumption of the emergy inputs used for the production of the output of these systems. The EER$_{\text{Y}}$ values for both rapeseed production systems were smaller than 1 and thus are unsatisfactory, especially when compared to production systems for moderate to high value products. To increase the EER$_{\text{Y}}$ of these systems, in addition to increasing the product price in the market, it may be possible to use various crop improvement techniques in the production phase so that the emergy input to the rapeseed farming systems is reduced, while maintaining or increasing levels of production.

3.2.4 Emergy Yield Ratio (EYR)—The emergy yield ratio (EYR) is obtained by dividing the emergy output by the purchased emergy inputs. Higher EYR values reflect a higher return on the invested emergy (Chen et al., 2006). A higher EYR value reflects higher dependence of the system on environmental resources as compared to the purchased resources. The EYR of the commercial and subsistence rapeseed production systems was 2.31 and 1.53, respectively (Table 1). In numerous emergy assessments, the EYR index is reported as one of the main indices. For instance, in a study carried out in China, the calculated EYR for rice and vegetable farms was 1.15 and 1.05, respectively (Lu et al., 2010). In the north of China, the EYR of corn farms was 1.20 (Zhang et al., 2012). In the banana (subsistence), papaya, guava, and wampee farms examined by Lu et al., (2009), the EYRs were reported to be 1.04, 1.16, 1.13, and 1.30, respectively. Since the EYR index is calculated using the ratio of the total emergy output (free and purchased) to the purchased input emergy, the higher the emergy of the free inputs the higher the EYR. This relationship is especially apparent for the commercial rapeseed production system at Khorramabad, where the large inputs of emergy from soil erosion and organic matter loss increased the EYR of this system.

3.2.5 Environmental Loading Ratio (ELR) and Modified Environmental Loading Ratio (ELR*)—The environmental loading ratio (ELR) expresses the pressure imposed on the environment by the purchased and local nonrenewable inputs. It reflects the potential extent to which the environmental services in the system are being utilized to create products of value to the larger system. The modified environmental loading ratio (ELR*) places purchased renewable resources in the denominator of the expression, making ELR* an inverse measure of sustainability assuming that greater use of renewable emergy equates to higher sustainability. Table 1 shows the calculations for these two indices. ELR* is obtained by calculating the ratio of nonrenewable and purchased nonrenewable emergy inputs to the purchased renewable inputs plus the renewable environmental inputs, while ELR is calculated using the ratio of purchased and local nonrenewable resources to local renewable resources (Ortega et al., 2002). The values for ELR and ELR* calculated for the commercial and subsistence systems were, respectively, 19.75 and 12.68 for ELR and 17.85 and 4.00, for ELR*. In the commercial system, only 0.5% of the total energy inputs to the system were from FR, which made the values of ELR and ELR* similar to each other. In contrast, in the subsistence system, the ratio of FR to the total energy inputs was around 13%, which led to a significant difference between the ELR and ELR * values.

In general, ELRs lower than 2 reflect relatively low levels of environmental pressure, an ELR higher than 2 and lower than 10 shows average environmental pressure. ELRs higher than 10 are indicative of high environmental stress (Cavalett et al., 2006; Brown and Ulgiati, 2004). Giannetti et al. (2011) reported that the ELR of coffee production in Brazil was 2.9 for the commercial ecosystem, while it was in the range between 0.39 and 2.06 in the reserved regions of the production site. They also reported low sustainability of the commercial coffee production system and mid-term and long-term sustainability for the other two systems. The ELR calculated in a study on the production of corn in the north of China was 10.62 (Zhang et al., 2005). Moreover, in another study in China, the ELR of wheat and corn was 10.59 and 0.47, respectively (Wang et al., 2014). The results from this research revealed that the ELR of wheat was 22 times that of corn, reflecting the considerable pressure imposed on the environment by the wheat production system. Lu et al. (2017) used ELR* to compare the sustainability levels of lotus, lotus-shrimp, and lotus-fish production systems and reported ELR values of 2.3, 2.8, and 2.4 for these three systems, respectively. They also compared the resulting ELR* values to conclude that the lotus production system was more sustainable than the other two systems.

3.2.6 Environmental Sustainability Index (ESI) and Modified Environmental Sustainability Index (ESI*)—In general, the environmental sustainability index (ESI) indicates whether it is possible to find a process that performs satisfactorily by imposing light pressure on the environment, while maintaining an acceptable yield (Odum, 1996). These sustainability indices allow for the inclusion of economic and environmental factors in the calculations. The enhancement of renewable environmental inputs and the reduction of nonrenewable emergy inputs will result in an improvement in ESI and ESI* in these systems. However, suppliers mainly focus on economic profitability, while environmental sustainability is also important for continued economic benefit. Hence, the best policy for rapeseed production is based on maintaining a balance between economic benefit and environmental sustainability. However, higher ESI and ESI* values mirror higher system sustainability (Asgharipour et al., 2019; Ulgiati and Brown, 1998).

ESI considers the pressure imposed on the environment. ESI values lower than 1 are indicative of heavy environmental pressures. Since the continuation of the heavy environmental pressure definitely has negative effects on the production system’s sustainability, it reduces production in the long run (Ulgiati and Brown, 1998). In the present study, the ESI and ESI* of the commercial system were 0.12 (0.117) and 0.13 and ESI and ESI* of the subsistence production system were 0.12 (0.121) and 0.38, respectively (Table 1). Similar values for ESI and ESI* for the commercial system were due to the low contribution of FR to the total emergy input (0.5%), while the large contribution of FR to the total emergy inputs (about 13%) led to the 3-fold difference between the values of ESI and ESI* for the subsistence system. The ESI and ESI* in both systems are below 1, indicating that with an increase in the energy consumption in both systems, heavy pressure is imposed on the environment. Some different factors are involved in the calculation of ESI and ESI* and also some are the same. The formulations are similar, so sometimes this gives similar values, for example, when FR is small. However, if FR is large, the values move away from each other. ESI* is not a consistent load measurement and cannot depend on meeting the underlying assumptions behind ESI, that is, the performance in the numerator is compared to the change in the denominator, where higher performance gained for the least damage to the environment results in a more sustainable system.

Although, there is no significant difference between the values of ESI and ESI *, however, the value of ESI * of the subsistence system is higher than that of the commercial system, mirroring the higher relative sustainability of the subsistence system. This relative sustainability difference is in line with the emergy inputs, and it seems that the large share of the environmental nonrenewable emergy resources used by the commercial system is the most important determinant of the sustainability difference between the two systems, which is effectively mirrored by the ESI*. An ESI smaller than 1, which reflects the exertion of heavy pressure on the environment during the production of crops has been reported in many studies. The ESI* value reported in a corn farm in China (Zhang et al. 2012) was 0.45, while the ESI* of banana, papayas, wampee, and guavas farms in China (Lu et al., 2009) varied from 0.03 to 0.30, respectively for a 11.1-hectare wheat farm and a 10.1-hectare multiple cropping farm (barley, clover, wheat, ryegrass, and several species of trees) in Denmark (Ghaley and Porter, 2013). ESI was also 0.15 for a corn farm in north China (Zhang et al., 2005), and ranged from 0.03 to 0.08 in five different bean production systems in Iran (Asgharipour et al., 2019). All ESIs in the systems examined are below 1, reflecting the heavy pressure put on the environment by different farming systems. However, ESI* helps distinguish the pressures exerted by the systems on the environment more clearly. For instance, in the research on five bean production systems by Asgharipour et al. (2019), the ecologic system with an ESI* of 1.48 was the most sustainable system, while the system with a considerable amount of nonrenewable inputs had an ESI* of 0.04 and was found to be the most unsustainable system as compared to the other four systems examined.

3.2.7 Emergy Index for Sustainable Development (EISD)—

The Emergy Index for Sustainable Development (EISD) assesses the market impact on the system's environmental sustainability. This index is, in fact, a combination of the EER_Y and ESI indices in the short and long terms. Higher EISD values reflect the higher sustainability of the system (Lu et al., 2003), when the economic exchange is considered in the emergy balance. In the present study, the EISD is calculated to assess the market impact on the output flow of the rapeseed production systems, which revealed that from this perspective the sustainability of the commercial system was almost 2.5 times that of the subsistence system. The EISD values in the commercial and subsistence rapeseed production systems were 0.11 and 0.04, respectively (Table 1). These values are somewhat lower than the EISD values of the higher commercial value fruit crops, wampee, guava, papaya, and banana grown in subsistence production systems in China that were, respectively, 0.73, 0.71, 0.55, and 0.24 (Lu et al.,2009).

3.2.8 Emergy Investment Ratio (EIR) and Modified Emergy Investment Ratio (EIR*)—

The emergy investment ratio is calculated based on the ratio of the purchased inputs to the free inputs of the system. A smaller EIR value shows higher dependence of the system output on the environmental resources of the system (Wang et al., 2014). This index shows the ratio of investment of the non-free inputs to the free inputs in a production system (Odum 1996; Lan et al., 2002). The EIRs of the commercial and subsistence rapeseed production systems were 0.76 and 1.86, respectively (Table 1). As a consequence of the considerable loss of soil organic matter in the commercial system, the EIR of the subsistence system was larger despite the higher investment of purchased inputs in the commercial system. One use of EIR is to show the attractiveness of future economic investments based on the availability of the remaining environmental resources in a system. However, in the case of extreme soil loss as a consequence of production, the stored value of the soil resource is being depleted, lowering the EIR by consuming stored natural capital. In this case, increasing purchased investments from outside may lead to system collapse, rather than further productive development. For this reason, a modified version the EIR was used in this paper.

To better examine the matching of outside investment in the rapeseed production systems relative to the free renewable environmental resources, a modified EIR (EIR*) was proposed in this study. The formula for EIR* is presented in Table 1. The values obtained for EIR* in the commercial and subsistence systems were 9.00 and 8.94, respectively. These values demonstrate the approximately equal investment of purchased inputs matching the free renewable environmental inputs in both the commercial and the subsistence systems. Cheng et al. (2017) carried out a study to compare three crops, chicken, and fish production systems and reported EIRs of 3.98, 4.63, and 5.87 for these systems, respectively. These EIR values are indicative of the lower EIR in the rapeseed crop system compared to the chicken and fish production systems. Cavalett and Ortega (2009) also reported an EIR of 1.25 in a study on soybean production systems in Brazil.

3.3 Total Factor Productivity (TFP)

Production can be increased by increasing the factors of production and by increasing productivity. Productivity refers to the more effective use of the production factors with better management approaches and newer methods of combining these factors. Due to the shortage of resources, increasing human demands, and severe competition in the global markets, improving productivity has transformed from a choice into a necessity. Measuring productivity also serves as a useful means of analyzing the sustainability of production systems over time (Coelli and Rao, 2005).

With an increase in the total factor productivity of a farming system, that system is considered to be more economically sustainable. The total factor productivity (TFP) is calculated by dividing the production index by the inputs index within a given period of time (Dashti et al., 2015). In the present study, the calculated TFPs of the commercial and subsistence systems were 0.396 and 0.146, respectively (Table 1). Hence, in the commercial and subsistence rapeseed production systems, 0.396 and 0.146 units of product were produced per unit of the total input, respectively. In their research on a potato production system, Dashti et al. (2015) reported a TFP of 0.011, which indicates the production of 0.011 tons of potato per average input unit. The total factor productivity of the commercial rapeseed system was 2.7 times that of the subsistence system. The reasons for the increase in production with the consumption of inputs in the commercial system is the use of crop improvement techniques such as selecting a cultivation date suiting the regional climate, using cultivars with high production potentials, using NPK fertilizers and micronutrients, using toxins for fighting the production loss factors, using pressurized irrigation and land integration, apportionment of costs per production unit, and the considerable technical knowledge of the farmers growing rapeseed (Eshgi and Neemati, 2012).

4. Discussion

4.1 The joint emergy and economic analyses of the indices

This examination of rapeseed production systems to assess their sustainability considered the use of local environmental resources, total factor productivity, and conversion of the input emergy into the market price of the product and the emergy that could be purchased with the money gained from its sale. This assessment was based on an analysis of the emergy and economic indices of two rapeseed production systems, i.e, commercial and subsistence. These thorough assessments resulted in a relatively comprehensive insight into the production of this product in both subsistence and commercial production systems. The emergy and economic analyses of the two systems measured the sustainability and productivity of both systems. However, the integration of these two analyses within a broader multidimensional horizon offered a more complete understanding of the production conditions in both systems.

According to the calculation of different indices for the purpose of comparison of the two rapeseed production systems in Khorramabad, the UEV, %R, ESI*, and EIR indices of the subsistence system were higher than similar indices of the commercial system, while the EER_Y, EYR, ELR, ELR*, EISD, and TFP indices of the commercial system were higher than similar values of the subsistence system (Table 1).

The higher UEV of the subsistence system may be attributed, primarily, to the considerable difference in the production of rapeseed (i.e., the economic yield) and the production of straw between the two systems, i.e, the yield of rapeseed and straw in the commercial system was about 5.2 times that of the subsistence system (Table 2).

The %R index of the subsistence system was higher than that of the commercial system. The smaller %R of the commercial system can be attributed to the considerable loss of soil organic matter (N_0). The input emergy from the loss of soil organic matter accounted for over 50.13% of the total resources used by the commercial system, while all purchased inputs (chemical fertilizers, fossil fuels, electricity, etc.) along with soil erosion provided 49.87% of the total emergy used in the commercial system. The large share of soil organic matter, as a nonrenewable resource input to the commercial system, is interesting, and from this fact it follows that adoption of proper management approaches to the production and preservation of soil organic matter can drastically improve the %R index of the commercial system. Agostinho et al. (2008) carried out a study in Brazil to compare three farms: one farm was managed with an ecological approach, and the other two were managed with the common management techniques. Their findings indicated that the %R of the ecologic farm was 59% and the %R of the two other systems was 27% on average. They believed fossil fuels represented the most important nonrenewable resource in the most commonly used systems, and they viewed a decrease in fossil fuels in the future as a serious threat to the sustainability of systems that rely on nonrenewable resources.

Although the EER_Y of the commercial system was higher than the subsistence system, it was below 1 in both systems. Furthermore, the emergy that could be purchased from sale of the rapeseed economic output in the market did not reach the breakeven point (i.e., it did not equal or exceed the system input emergy) in either the commercial or the subsistence systems. The commercial system converted 94% of the input emergy into emergy purchased by the money received for the commodity, whereas the conversion rate was only 31% for the subsistence system. The system economic output (i.e., the emergy of the rapeseed yield per unit area) and the product price were included in the assessment of the input emergy EER_Y, explaining the comprehensiveness of this index. Hence, a decrease in the system input emergy increased this index, as did increased production per unit area and a higher market price for rapeseed. Improvement in the EER_Y index results in higher sustainability of the production system. Moreover, since rapeseed yield on the commercial site was close to the production potentials of the cultivars, if all production conditions remain unchanged except for the guaranteed price for the purchase of rapeseed, which is 27,830 IRR per kilogram, a price equal to 29,000 IRR must be set to establish a link between EER_Y and Y_M (Table 1) so that EER_Y equals 1 (the breakeven point of the required emergy input).

The higher EYR of the commercial system reflects the greater use of environmental (renewable and nonrenewable) resources relative to purchased resources. In other words, in the commercial system, dependence on purchased resources is lower than the dependence on free environmental resources. Moreover, although the input of the free environmental resources to the commercial system was 2.74 times that of the subsistence system, less than one-tenth of the free environmental resource input of the commercial system was made-up of renewable resources and the rest of the input was supplied by nonrenewable environmental resources.

ELR and ELR* have both been characterized as measures of environmental pressure in past studies; however, Campbell and Garmestani (2012) have pointed out the problems with ELR* as a consistent measure of loading and they showed that it is actually a consistent inverse measure of sustainability. Our considerations of ELR* as a loading measure should be further examined within the limits placed on this interpretation by these insights. The ELR is the sum of the total purchased inputs (FR and FN) together with the nonrenewable environmental inputs (N_0) compared to the renewable inputs from the environment (R). If the quantity and manner of using purchased inputs (for example, the use of agricultural machinery, chemical fertilizers, chemicals, labor, etc.) leads to an increase in N_0, ELR and the environmental burden increase. Whereas, the ELR and the environmental burden will be reduced, if the consumption of purchased inputs increases R or decreases N_0. ELR* gives the ratio of nonrenewable inputs (FN and N_0) to renewable inputs (FR and R). Therefore, the value of this index decreases with an increase in the proportion of renewable inputs and increases with the increasing proportion of non-renewable inputs. Both the ELR and ELR* values reflect aspects of the pressure exerted on the environment by the commercial rapeseed production system. According to the ELR value, the environmental pressure applied by the commercial rapeseed ecosystem is 1.56 times that of the subsistence system. Moreover, based on ELR*, the pressure exerted on the environment by the commercial system is 4.46 times the subsistence production system. In their research, Agostinho et al. (2008) stated that the pressure exerted on the environment by a farm managed using the conventional model was 5.68 times that of the ecologic farm.

Although the ESI and ESI* indices are introduced and classified as emergy indices, they also express a type of economic cost-benefit ratio in terms of the application of the inputs (free or purchased). In addition, since the EYR, ELR, and ELR* indices are involved in the calculation of the values of these two sustainability indices, a decrease in the use of the purchased inputs and an increase in the use of renewable resources (especially the free renewable resources) improve the ESI index. The effect of greater renewable emergy inputs is seen in the 3-fold larger ESI* index of the subsistence rapeseed production system as compared to the commercial system.

EISD is among the indices that are larger in the commercial system than in the subsistence system. This index may be more comprehensive than ESI, because the economic outputs and the market impact are also considered, along with the emergy inputs in the calculation of this index. According to the EISD index when compared to the ESI index, the commercial system is found to be more sustainable than the subsistence system, because it includes the effects of market exchange on system sustainability.

The larger EIR of the subsistence system, as compared to the commercial system, also shows the heavy production costs in this ecosystem. In other words, based on the resulting EIR value, the production of rapeseed in the subsistence system resulted in a smaller competitive advantage and relative advantage in attracting further investment compared to the commercial ecosystem due to lower use of nonrenewable environmental resources, N_0, in this system. However, judgments must be made more carefully based on the calculated EIRs. According to Campbell and Laherrere (1998), the estimation of the costs and prices of the environmental impacts of nonrenewable resources will become possible in the future. Hence, the production of commodities in the process of market globalization will be costly. More exactly, about 90% of the free environmental inputs to the commercial system (loss of organic matter and soil erosion) are supplied from nonrenewable environmental resources, which is the reason for the lower EIR and implied better economic performance (competitiveness) of the commercial system. This heavy dependence on nonrenewable environmental resources (even if they are free) will not be sustainable in the future. In light of this discussion and since lower values of EIR are judged to be more economically competitive, because the free environmental resources are less intensively matched with economic investments, we modified EIR to EIR*, where EIR* = (FN+FR)/R. This index is defined as the ratio of purchased resources to the renewable inputs and it is recommended as a more direct comparison of the matching of purchased inputs to the renewable environmental resources; therefore, we think that it better shows the relative competitive advantages offered by these two systems. EIR* is proposed here, because even though N_0 is not paid for economically, i.e., it is free; however, it is not worthless and considerable costs may be incurred in the future by making investment decisions today as if it is not a limited resource and always will be free. Thus, decisions based on EIR*, instead of EIR take away the advantage in economic attractiveness for future investments given by over exploitation of the currently free, but ultimately limited soil resource.

Based on the TFP formula, there is a direct link between this index and the economic output (rapeseed yield) per unit area, as well as an inverse relationship between TFP and purchased inputs. In addition, in the commercial system, TFP is 2.7 times this index in the subsistence system (Table 1). In other words, in the commercial system, the production is 2.7 times that of the subsistence system per unit of purchased input. The environmental inputs are not considered in the calculation of TFP and other economic indices. In addition, systems are compared based on the economic indices in the short term and the immediate benefits determined. Hence, environmental sustainability, which affects economic sustainability in the long run, is overlooked. Moreover, the use of production methods and techniques that increase production and result in the replacement of purchased inputs with natural and cheaper inputs improve TFP in the long run.

4.2 The recommended management methods for improving farm production systems

The following management guidelines and general policies to improve the agricultural farming systems including the crop production systems are presented here based on the results from this research.

i. Since the input emergy from organic matter loss and soil erosion made-up a large share of the inputs to both systems in this research, the practice of proper management techniques is recommended to protect the soil and preserve its organic matter. The outcome would result in the improvement of many soil properties and a decrease in the rate of loss of organic matter and soil erosion. In other words, the following measures reduce the nonrenewable input to the commercial system and increase this ecosystem's sustainability: by reducing the severity of organic matter degradation (e.g. through a decrease in tillage operations), increasing the production of herbal substances in farms, preventing the burning of plant material, which remains the biggest source of soil organic matter replenishment, switching to plants that produce herbal substances and a large biomass, practicing recommended grazing, using different organic matter sources such as manure, reinforcing the soil microorganism populations, and improving the water storage capacity and water permeability (Mirzashahi and Bazargan, 2015).

ii. Reducing consumption of chemicals (fertilizers and toxins) while maintaining high productivity can be achieved through the total management of production units by conducting soil tests, using meteorological data, applying crop improvement methods and techniques, and using the proper equipment and mechanization operations. The amount of fertilizer required by many plants, including rapeseed, is recommended based on the expected yield, regional climate, the soil organic carbon content, access to water, and concentration of different elements in soil (Noorgholipoor et al., 2014). The consumption of chemical fertilizers, regardless of the other factors mentioned, also results in a decrease in sustainability. For example, on the subsistence farming site studied in this research, the farmer did not use chemical fertilizers based on soil tests, his technical knowledge and meteorological data. Instead, the farmer used various amounts of chemical fertilizers freely. However, based on the rapeseed nutrients information table (Noorgholipoor et al., 2014) and the yield expected by the farmer from this site (1.5 tons per hectare), too much chemical fertilizer was used on the farm, resulting in an increase in the UEV index of the product and a decrease in the effectiveness of this system in producing an emergy yield. If the amount of fertilizers (chemical and manure) used on this farm had been determined based on soil tests, climatic conditions, and the expected yield, the dependence on chemical fertilizers, environmental pollution, and production costs would have been reduced and some of the measured sustainability indices an the subsistence site would have increased.

iii. It is necessary to price crops based on the trend and specifications of production and the crop quality to offer economic and environmental motives to the farmers, who use more renewable resources than nonrenewable resources in the course of production.

iv. Another strategy is to encourage the approval and promotion of the integration of small farmlands into the development strategy for the purpose of increasing production through total management and implementation of the Best Management Practices (BMPs). For example, according to Cavalett et al. (2006) the production of corn, pigs, and fish through integrated systems in Brazil reduced dependence on purchased inputs and the use of free nonrenewable resources, and increased the use of renewable environmental energies. Based on the results from the present research, the increased use of production systems on integrated farmlands and large lands most probably increases production, if methods of reducing organic matter decay are implemented. Besides, if organic matter loss declines as a source of nonrenewable environmental input to the commercial rapeseed production system, most sustainability indices are changed and improve in favor of increased system sustainability.

v. There is a need to reconsider and increase the guaranteed price for rapeseed at state auctions to ensure sustainable production and support the further development of this strategic product in Iran. Furthermore, implementing policies to develop and expand technical knowledge about how to improve rapeseed yield per unit area are also needed to ensure this result. Increasing rapeseed prices in the commercial and subsistence systems and using crop improvement techniques for increasing production per unit area calls for the integration of minor land holdings into larger land holdings, especially in the subsistence system, to increase sustainability.

vi. Finally, for a more comprehensive assessment of the sustainability of production systems, field evaluations must be accompanied by assessments of external environmental impacts, such as the generation of different types of pollution, and the placement of limitations that may be needed on the production systems.

5. Conclusion

The present research goal was to compare the ecological-economic sustainability of two rapeseed production systems in Khorramabad, Iran, through the application of emergy and economic analyses. This research was an attempt to find, introduce, and promote a production model by searching the existing models that not only meet environmental requirements, but also guarantee maximum economic benefit. Of the two rapeseed production models examined, the higher environmental sustainability, higher renewable emergy use, and smaller environmental load as reflected by the ESI*, %R, ELR, and ELR* indices were found in the subsistence system and indicate the higher ecological sustainability of this system. In contrast, the larger emergy exchange ratio, the higher sustainability when considering market impacts (ecological-economic sustainability), the lower emergy consumption per unit of output (higher efficiency of production), and higher total factor productivity demonstrated the higher relative advantage of the commercial system based on the EER_Y, EISD, UEV, and TFP indices.

The large environmental load, low renewable emergy ratio, and lower sustainability of the commercial system are mainly caused by soil organic matter loss as an input emergy from the environmental nonrenewable resources. Hence, this input accounted for 47.34% of the total inputs to this cultivation model. Therefore, more focus on scientific soil management solutions, especially prevention of soil organic matter loss, in highly mechanized models can significantly contribute to the sustainability of these systems. In addition, the low emergy exchange ratio in the market is mainly caused by the low production efficiency (lower UEV for rapeseed) and low total factor productivity of the subsistence system, which could be attributed to the low production per unit area and the relatively high emergy of the purchased inputs (including chemical fertilizers) used in this ecosystem. The sustainability of the subsistence cultivation systems can be improved by advancing the farmers’ technical knowledge, reducing the supply of purchased inputs from nonrenewable sources, and relying on more renewable environmental resources based on the expected yield, which was less than half the plant yield potential. Also, it would be interesting to develop a system that integrates the strengths and benefits of both systems into a single crop production system. In this case, superior economic production and the high profitability associated with the commercial system would be combined with the lower harmful impacts on the environment, the lower soil erosion and less loss of soil organic matter as found in the subsistence system.

Finally, in this research, emergy and economic analyses were carried out in parallel to compare the sustainability of two rapeseed production systems in Khorramabad, and these results can be extended to similar areas of rapeseed production throughout Iran. However, other types of production systems in Iran and in other parts of the world should also be studied to gain a more comprehensive, general understanding of the sustainability of rapeseed production systems. Furthermore, in addition to the standard emergy indices analyzed in this research, the modified EIR index, EIR*, was proposed and used to show the ratio of purchased resources to the free renewable inputs from the environment as a measure of the relative attractiveness of investment in the two systems. EIR* maybe useful in future assessments and analyses, where potentially renewable environmental resources are being used in an extremely nonrenewable manner, resulting in a low EIR that implies economic advantage over the short run, but portends over exploitation and collapse in the long run.

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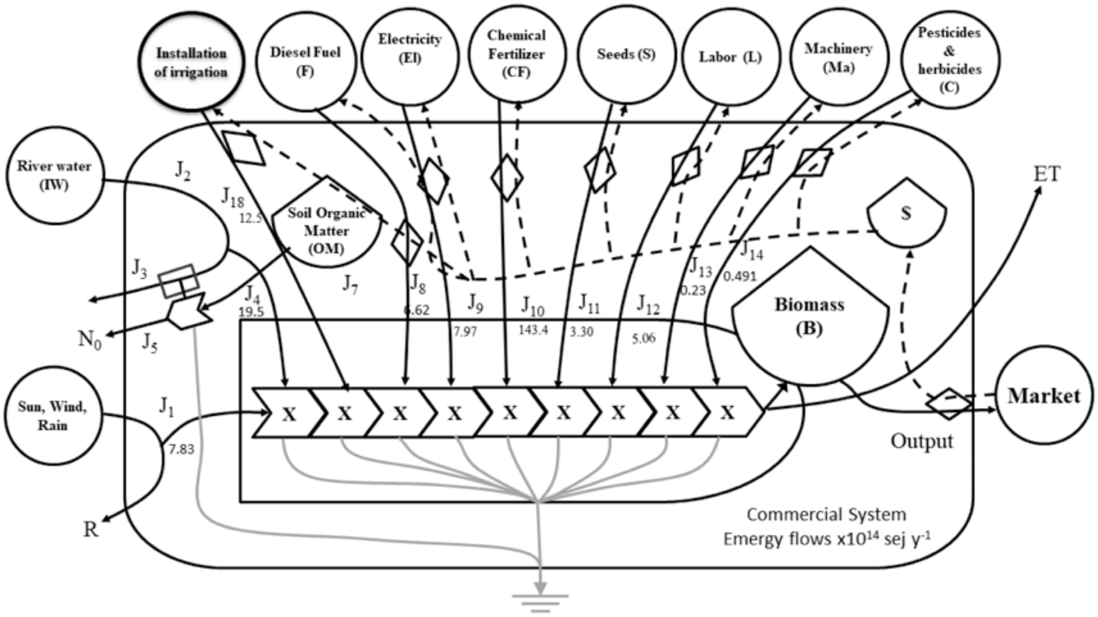

Fig. 1.

Summary diagram of the emergy flows in commercial production system for rapeseed

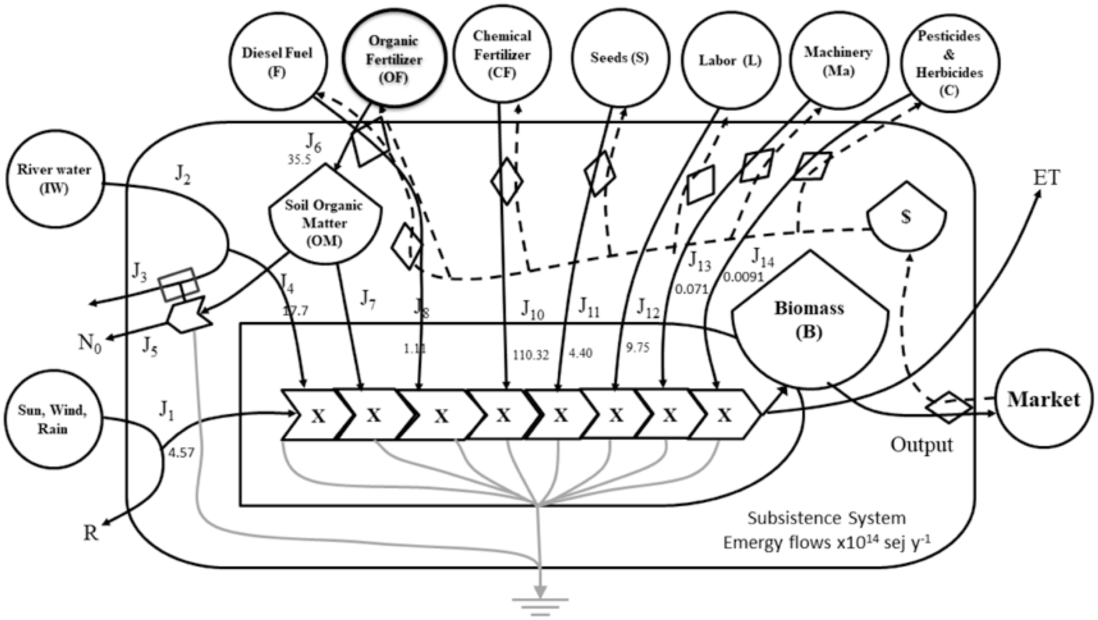

Fig. 2.

Summary diagram of the emergy flows in subsistence production system for rapeseed

Table 1-

Emergy-based and economic indices of commercial and subsistence systems for rapeseed production

Expression	Commercial	Subsistence
UEV_E = U/E (sej J^{-1}) Transformity	2.60E+05	8.02E+05
R (%) = (R+FR)/U *100 Percent Renewable Energy	5.30	19.90
EER_Y = Y_M/U Emergy Exchange Ratio	0.94	0.31
EYR = (U /(FN + FR)) Emergy Yield Ratio	2.31	1.53
ELR = (FN + N_0 + FR) / R Environmental Loading Ratio	19.75	12.68
ELR* = (FN + N_0) / (R + FR) Modified ELR, an inverse measure of sustainability	17.85	4.00
ESI= (EYR / ELR) Environmental Sustainability Index	0.117	0.121
ESI* = (EYR/ ELR*) Alternate Sustainability Index	0.13	0.38
EISD = EYR×EER_Y/ELR Environmental Index of Sustainable Development	0.11	0.04
EIR = (FN + FR)/ (R +N_0) EIR (purchased without service to free)	0.76	1.86
EIR* = (FN + FR) / R EIR(purchased without service to free renewable)	9.00	8.94
$TFP = \frac{TP_i}{\sum_j S_j X_{ij}}$ Total Factor Productivity	0.396	0.146

U= FN + FR +R+ N_0

E = Economic yield (J)

Y_M =Market value of the product’s economic yield.

TP_i = The total amount of rapeseed production in the *i* farm

X_{ij} = The amount of each input on the *i* farm

S_j = The average share of the cost of each input in total cost of production units

Table 2-

Natural and economic flows of the commercial and subsistence production systems for rapeseed in units ha^{-1}. The unit and the renewability factor (fraction renewable energy) and the symbols keying the values in this table to Figure 1 are also given.

	Unit	Symbol in diagram	Ren. factor	Commercial	Subsistence
Renewable environmental inputs					
Solar energy	J	J_1	1	4.00E+13	3.28E+13
Wind, kinetic energy	J	J_1	1	6.42E+09	5.26E+09
Rain, chemical	J	J_1	1	3.48E+10	2.03E+10
Evapotranspiration	J	J_{15}	1	3.48E+10	2.46E+10
River water		J_4	1	5.39E+10	4.90E+10
Non-renewable environmental inputs					
SOM reduction	J		0	2.09E+11	2.85E+10
Soil erosion	g	J_5	0	1.42E+06	3.21E+06
Purchased inputs					
Human labour	J	J_{12}	0.1	2.28E+08	4.39E+08
Machinery	g	J_{13}	0	2.28E+03	7.00E+02
Fossil fuel and lubricants	J	J_8	0	7.70E+09	1.29E+09
Nitrogen fertilizer	g	J_{10}	0	2.50E+05	1.50E+05
Phosphorus fertilizer	g	J_{10}	0	1.50E+05	1.50E+05
Potash fertilizer	g	J_{10}	0	1.50E+05	5.00E+04
Sulphur fertilizer	g	J_{10}	0	1.00E+05	1.00E+05
Micro fertilizer	g	J_{10}	0	3.00E+03	0.00E+00
Organic fertilizer	g	J_6	0.8	0.00E+00	1.20E+07
Pesticide	g	J_{14}	0	1.00E+03	5.00E+01
Herbicide	g	J_{14}	0	1.60E+03	0.00E+00
Electricity	J	J_9	0.01	3.45E+09	0.00E+00
Installation of irrigation system	Rials	J_{18}	0	5.00E+06	0.00E+00
Seed	Rials	J_{11}	0.43	1.32E+06	1.76E+06
Output					
Economic yield	g	J_{16}		5.70E+06	1.10E+06
Economic yield	J	J_{16}		1.59E+11	3.08E +10
Straw yield	g	J_{17}		1.03E+07	1.98E+06
Straw yield	J	J_{17}		1.60E+11	3.10E+10

Energy equivalent for rapeseed straw is 15.57MJ.kg (Mousavi-Avval et al., 2011)

Table 3-

Emergy synthesis and input structure of the commercial and subsistence rapeseed production systems (sej ha^{-1}) except as noted.

	Unit	Transformity	Refs. for transformity	Emergy (sej ha^{-1})		Distribution	
				Commercial	**Subsistence**	**Commercial**	**Subsistence**
Renewable environmental inputs(R)							
Solar energy	J	1.00E+00	Definition	4.00E+13	3.28E+13	0.10%	0.13%
Wind, kinetic energy	J	1.25E+03	Campbell, and Erban, 2017	8.03E+12	6.58E+12	-	-
Rain, chemical	J	2.25E+04	Campbell (man.)	7.83E+14	4.57E+14	-	-
Evapotranspiration	J	2.88E+04	Campbell (man.)	1.00E+15	7.08E+14	-	-
River water (chemical potential)	J	3.61E+4	Campbell (man.)	1.95E+15	1.77E+15	-	-
Subtotal				**1.99E+15**	**1.80E+15**	4.81%	7.31%
Renewable environmental inputs used in a nonrenewable way (N_0)							
Soil organic matter reduction	J	9.36E+04	Brandt-Williams, 2002	1.96E+16	2.67E+15	47.34%	10.2%
Soil mineral erosion	g	1.27E+09	Odum 1996	1.80E+15	4.08E+15	4.36%	16.53%
Subtotal				**2.14E+16**	**6.74E+15**	51.71%	27.35%
Purchased inputs(FR)&(FN)							
Human labour	J	2.22E+06	Lu et al., 2009	5.06E+14	9.75E+14	1.22%	3.95%
Machinery	g	1.01E+10	Campbell et al., 2005	2.30E+13	7.07E+12	0.06%	0.03%
Fossil fuel and lubricant	J	8.60E+04	Bastianoni et al., 2009	6.62E+14	1.11E+14	1.60%	0.45%
Nitrogen fertilizer	g	3.09E+10	Brandt-Williams, 2002	7.73E+15	4.64E+15	18.70%	18.80%
Phosphorus fertilizer	g	2.82E+10	Brandt-Williams, 2002	4.23E+15	4.23E+15	10.24%	17.15%
Potash fertilizer	g	2.23E+09	Odum, 1996	3.35E+14	1.12E+14	0.81%	0.45%
Sulphur fertilizer	g	2.05E+10	Campbell et al. (2014)	2.05E+15	2.05E+15	4.96%	8.31%
Micro fertilizer	g	3.91E+09	Lan et al., 2002	1.17E+13	0.00E+00	0.03%	0.00%
Organic fertilizer	g	2.96E+08	Odum, 1996	0.00E+00	3.55E+15	0.00%	14.41%
Pesticide	g	1.89E+10	Hu et al., 2010	1.89E+13	9.45E+11	0.05%	0.00%
Herbicide	g	1.89E+10	Hu et al., 2010	3.02E+13	0.00E+00	0.07%	0.00%
Electricity	J	2.31E+05	This work	7.97E+14	0.00E+00	1.93%	0.00%
Installation of irrigation system	Rials	2.50E+08	Asgharipour et al. (man.)	1.25E+15	0.00E+00	3.03%	0.00%
Seed	Rials	2.50E+08	Asgharipour et al. (man.)	3.30E+14	4.40E+14	0.80%	1.78%
Subtotal				**1.80E+16**	**1.61E+16**	43.49%	65.34%
Total(U)				**4.13E+16**	**2.47E+16**	100.00%	100.00%
Output(Y)							
Economic yield(E)	g	sej g-1	This work	7.24E+09	2.25E+10		
Economic yield(E)	J	sej J-1	This work	2.60E+05	8.02E+05		

	Unit	Transformity	Refs. for transformity	Emergy (sej ha^{-1})		Distribution	
				Commercial	Subsistence	Commercial	Subsistence
Straw yield	g	sej g-1	This work	4.01E+09	1.25E+10		
Straw yield	J	sej J-1	This work	2.60E+05	7.97E+05		

[a] Transpiration is an integrated measure of all the renewable inputs required to support plant production (Odum, 1996), therefore it was chosen to represent R, to avoid double counting. In our view, the emergy of the solar radiation supporting photosynthesis must also be included for a complete accounting of the emergy of transpiration supporting rapeseed production.