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Evaluating Energy Dynamics: A Comparative Analysis of Pulses Production Systems in Iran

Salman Koocheki[a]

Abstract

The examination of energy dynamics within agroecosystems emerges as a promising methodology for evaluating environmental challenges and their intricate connections to sustainability. This study seeks to delineate a comprehensive comparative analysis among bean, lentil, irrigated chickpea, and dryland chickpea farms. The primary focus is on assessing key parameters such as energy efficiency, energy productivity, benefit-to-cost ratio, and the extent of renewable energy utilization within these agricultural systems. Data were collected from 18 bean, 27 lentil, 24 irrigated chickpea and 46 dryland chickpea growers, using a face-to-face questionnaire. The results revealed that the total energy requirement were for bean 23666.8 MJ ha^{-1}, for lentil 14114.79 MJ ha^{-1}, for irrigated chickpea 15756.21 MJ ha^{-1}, and for dryland chickpea 2630.12 MJ ha^{-1}. The study reveals that the aggregate energy inputs, encompassing direct, indirect, renewable, and non-renewable sources, were distributed as follows among the examined crops: 67% for bean, 33% for lentil, 30% for irrigated chickpea, and 70% for dryland chickpea farms. In terms of energy use efficiency, the findings indicate values of 1.81 for bean, 1.79 for lentil, 1.21 for irrigated chickpea, and notably higher at 2.78 for dryland chickpea. In the context of benefit-to-cost ratios, the study demonstrates values of 6.18, 6.15, 3.71, and 8.10 for bean, lentil, irrigated chickpea, and dryland chickpea farms, respectively. Notably, the results indicate that dryland chickpea emerges as the most energy-efficient option. Among the irrigated crops under examination, bean not only exhibits superior energy efficiency but also stands out as the most economically beneficial choice based on the study's findings.

Keywords: Energy Productivity, pulses production
JEL Codes: O13

1. INTRODUCTION

Pulses, comprising staples in the diet of impoverished rural and urban communities, hold particular significance in developing countries. Concurrently, in developed nations, pulses, including Bean (Phaseolus vulgaris L.), lentil (Lens culinaris L.), and chickpea (Cicer arietinum L.), assume the status of major cash crops. These leguminous varieties, encompassing Bean, lentil, and chickpea, stand out as globally paramount pulses, contributing significantly to both sustenance and economic prosperity. In Iran, the total cultivated area spans approximately 697,000 hectares. Within this agricultural landscape, chickpea, lentil, and bean hold prominent shares, accounting for 61.13%, 21.94%, and 14.26% of the cultivated expanse, respectively. The Khurasan Razavi province in Iran stands as a key pulse-producing region, boasting a substantial cultivating area of approximately 13,500 hectares. Within this province, pulses play a pivotal role, serving as a primary source of raw food materials for numerous rural and urban households. Contemporary agricultural production is heavily dependent on the utilization of non-renewable energies, notably fossil fuels (Erdemir, 2006). The consumption of fossil energy not only induces direct adverse environmental effects through the emission of CO_2 and other combustion byproducts but also contributes to indirect negative impacts on the environment, including the reduction of biodiversity. It is noteworthy that the extensive use of cost-effective fossil energy has far-reaching consequences on the environment, influencing factors such as ecological diversity. The interdependence of energy, economics, and the environment is a well-acknowledged phenomenon (Refsgaard et al., 1998; Pimentel et al., 1994). The intricate relationship among these factors underscores the importance of adopting sustainable practices that balance the needs of agricultural production, economic considerations, and environmental preservation. Furthermore, a closely intertwined relationship exists between agriculture and energy. The current productivity and profitability of agricultural practices hinge significantly upon energy consumption. Consequently, the quest for agricultural production methods characterized by enhanced energy productivity remains just as relevant today as it was two decades ago (Refsgaard et al., 1998). The ongoing pursuit of methods that optimize the relationship between energy input and agricultural output underscores the evolving landscape of sustainable and efficient agricultural practices. Within agroecosystems, the energy needs are categorically divided into four distinct groups: direct and indirect, non-renewable and renewable. Specifically, direct energy is essential for the execution of numerous tasks, encompassing activities such as land preparation, irrigation, threshing, harvesting, and the transportation of both agricultural inputs and farm products (Singh, 2000). This comprehensive classification allows for a nuanced understanding of the diverse energy requirements associated with various facets of agroecosystem management. Indirect energy, as a component within agroecosystems, encompasses the energy expended in the construction, packaging, and transportation of essential

[a] Ferdowsi University of Mashhad, Mashhad, Iran

elements such as fertilizers, biocides, and machinery (Ozkan et al., 2004). This category sheds light on the broader energy footprint associated with the production and distribution of key inputs crucial to agricultural practices, offering a holistic perspective on energy utilization in the agricultural sector. Non-renewable energy within agroecosystems encompasses essential resources such as diesel, chemicals, fertilizers, and machinery, highlighting the dependence on finite and exhaustible sources (Mohammadi et al., 2008). In contrast, renewable energy sources in this context include human labor, water, seeds, and farmyard inputs, underscoring the reliance on sustainable and replenishable elements (Mohammadi et al., 2008). This distinction between non-renewable and renewable energy sources provides a critical lens through which to assess the ecological sustainability and resilience of agricultural practices. The widespread utilization of both direct and renewable energy resources not only augments energy supply but also plays a pivotal role in enhancing energy efficiency. This concerted effort holds the potential to make a significant and valuable contribution towards achieving targets for sustainable energy development (Streimikiene et al., 2007). By prioritizing direct and renewable energy sources, agricultural practices can align with broader sustainability goals, ensuring a more efficient and environmentally conscious approach to energy utilization in the pursuit of long-term energy development objectives. The escalating annual increase in energy consumption within the agricultural sector has raised concerns, particularly as intensified energy use has been linked to significant human health and environmental issues. Recognizing the imperative to address these challenges, there is a pressing need to curtail reliance on fossil energy inputs in agricultural systems. Such a shift holds the potential not only to mitigate adverse impacts on human health and the environment but also to contribute substantially to the reduction of carbon dioxide emissions associated with agricultural practices. Implementing measures to reduce dependence on fossil energy represents a critical step towards fostering sustainable and environmentally responsible agricultural systems.

Indeed, the judicious and effective utilization of energy inputs has emerged as a crucial aspect of sustainable farming (Karimi et al., 2008; Rathke and Diepenbrock, 2006). It stands as a fundamental prerequisite for sustainable agriculture, reflecting the imperative to balance agricultural productivity with environmental responsibility. The escalating demand for energy in the agricultural sector is a direct response to population growth, constrained arable land availability, and an increasing desire for elevated standards of living. By prioritizing efficient energy use, agriculture can align itself with the principles of sustainability, fostering practices that are both environmentally conscious and economically viable. The persistent need for escalating food production has led to the intensive utilization of chemical fertilizers, pesticides, agricultural machinery, and other natural resources. Consequently, promoting the efficient use of energy in agriculture becomes paramount not only for economic reasons but also as a proactive measure to mitigate environmental issues. By optimizing energy usage, agriculture can play a crucial role in preventing the depletion of natural resources and minimizing the environmental impact associated with intensive agricultural practices. This approach aligns with the overarching goal of fostering sustainable agriculture, where economic productivity is harmonized with environmental stewardship to create a balanced and resilient production system (Erdal et al., 2007).

The application of input-to-output energy analysis proves instrumental in evaluating the impact of production systems on the environment and gauging the efficiency of energy utilization (Franzluebbers and Francis, 1995). This analytical approach serves as a valuable tool in assessing the intricate relationship between energy inputs and the resulting outputs within various production systems. By scrutinizing this energy balance, researchers and practitioners can gain insights into the environmental implications of different agricultural practices and identify opportunities for enhancing energy efficiency within the broader context of sustainable production. The rate of energy consumption in agriculture is contingent upon a range of environmental factors, including soil quality, climatic conditions, the quantity of inputs utilized, and the specific techniques employed in the production process (FAO, 2005). This acknowledgment underscores the dynamic and multifaceted nature of energy utilization in agriculture, where the interplay of environmental variables and management practices significantly influences the overall energy requirements for productive farming. Understanding and considering these factors are essential for devising strategies that optimize energy use while accounting for the inherent variability in agricultural ecosystems. In developing nations such as Iran, fostering agricultural growth is imperative for nurturing economic development and addressing the increasing demands of a growing population. Over the last three decades, there has been a noteworthy shift from subsistence farming to commercial farming, marking a transformation in the predominant mode of agricultural production in Iran. This transition underscores the evolving agricultural landscape in response to economic imperatives and the need to sustainably meet the food requirements of a expanding populace. The agricultural sector serves as the second-largest employer in Iran, playing a significant role in contributing to the Gross Domestic Product (GDP). Notably, the share of agriculture in the GDP stood at 10.87%. In response to the global upswing in energy prices in recent years, Iranian entities have proactively implemented measures to curtail fuel and energy consumption. This strategic approach reflects a commitment to resource efficiency and aligns with broader economic considerations, emphasizing the importance of sustainable practices within the Iranian agricultural landscape.

To address the escalating energy demands across all sectors of the economy, Iran has initiated measures such as rationing subsidized petrol and diesel for consumers. Additionally, concerted efforts are underway to enhance the overall efficiency of energy use. These strategies are crucial in mitigating the increasing strain on energy resources. Importantly, there is a growing awareness among the populace regarding the implications of these policies on energy usage in Iran. This heightened awareness reflects a broader understanding of the need for responsible energy management and its impact on both the economy and the environment. Numerous studies have delved into comprehensive analyses, encompassing input and output energy evaluations, along with economic assessments, to ascertain the energy efficiency of diverse crop productions. Notable examples include investigations into chickpea, irrigated and dryland wheat, barley in Iran, dry bean, and canola in Turkey (Ozkan et al., 2004). Additionally, research has been conducted on rice in Malaysia (Bockari Gevao et al., 2005) and maize and sorghum in the United States (Mohammadi et al., 2008). These studies provide valuable insights into the intricate relationship between energy inputs, crop yields, and economic factors, contributing to a nuanced understanding of sustainable and efficient agricultural practices across different regions. The absence of published studies on the energy and economic analysis of pulse production in Iran underscores a notable gap in the existing literature. Given the global significance of pulses for both food and feed, a comprehensive understanding of the energy consumption associated with their production is imperative. The lack of such studies hinders efforts to enhance energy use efficiency in pulse production systems. Exploring and documenting the energy dynamics and economic aspects of pulse cultivation in Iran would not only contribute valuable insights to the scientific community but also aid in the development of informed and sustainable agricultural practices specific to pulse crops in the region.

2. MATERIAL AND METHODS

The present study was conducted in Khorasan Razavi province which is located northeast of Iran, within 30024 and 38017 north latitude and 55017 and 61015 east longitude. Total area of the province is 12842000 ha and the total farming area of bean, lentil and chickpea is 13486 ha consisting of 916 ha bean, 2245 ha lentil, 2108 ha irrigated chickpea and 8217 ha dryland chickpea. In order to determine the relation between pulse yield and energy consumption, required data were collected from growers by using a face to face questionnaire. In addition to the data obtained by surveys, previous studies of related organizations such as Food and Agricultural Organization (FAO) and Ministry of Agriculture of Iran (MAJ) were also utilized during this study. The number of operations involved in the pulse production systems, and their energy requirements influence the final energy balance. The evaluation of energy efficiency in the agricultural system was conducted using the energy ratio, calculated as the relationship between output and input, as outlined by Alam et al. (2005). This energy ratio serves as a key metric for assessing the effectiveness of energy utilization within the agricultural production processes under study. By quantifying the ratio of output to input energy, researchers can gain valuable insights into the overall efficiency and sustainability of the agricultural systems being analyzed. Human labor, machinery, diesel oil, fertilizer, pesticides and seed amounts and output yield values of bean, lentil, irrigated chickpea and dryland chickpea have been used to estimate the energy ratio. Energy equivalents shown in Table 1 were used for estimation. The sources of mechanical energy used on the selected farms included tractors and diesel oil. The mechanical energy was computed on the basis of total fuel consumption (l ha^{-1}) in different farm operations. To quantify the energy consumed in the agricultural operations, conversion factors were applied, and the results were expressed in megajoules per hectare (MJ ha^{-1}), following the methodology described by Tsatsarelis (1991). This conversion allowed for a standardized and comparable measure of energy consumption across different inputs and processes involved in the cultivation of bean, lentil, irrigated chickpea, and dryland chickpea. Expressing the energy consumption in MJ ha^{-1} provides a common unit of measurement, facilitating the analysis and comparison of energy use efficiency in the studied pulse production systems.

The study compiled fundamental data regarding energy inputs and crop yields for bean, lentil, irrigated chickpea, and dryland chickpea, transferring this information into Excel spreadsheets. Subsequently, the dataset underwent analysis using the SPSS program. Key energy-related metrics, including energy use efficiency, energy productivity, specific energy, and net energy, were computed based on established input and output energy equivalents, drawing upon the methodology outlined by Bockari Gevao et al. (2005). These calculated metrics provide a robust framework for assessing and comparing the energy dynamics and efficiency of the different pulse production systems under investigation. In the energy analysis of pulse production, indirect energy encompasses the energy embedded in various inputs such as seeds, chemical fertilizers (NPK), herbicides (Treflan and Basagran), pesticides (Diazinon), fungicides (Carboxin), and machinery. On the other hand, direct energy factors in human labor, diesel, electricity, and water utilized during pulse cultivation. Non-renewable energy sources include diesel, electricity, chemical pesticides, chemical fertilizers, and machinery, while renewable energy comprises human labor, seeds, and water. This detailed categorization allows for a thorough examination of the diverse energy components involved in pulse production, distinguishing between indirect and direct sources as well as non-renewable and renewable elements. In the economic analysis of pulse production systems, economic inputs primarily encompass variable costs. These variable costs of production comprise current expenses such as chemicals, fuel, human labor, and electricity. On the economic output side, pulse production systems account for both grain and straw yields. This consideration of variable costs and the dual nature of economic output provides a comprehensive framework for evaluating the economic viability and efficiency of pulse cultivation. The inclusion of variable costs and output components like grain and straw yield ensures a thorough assessment of the economic aspects associated with pulse production.

3. RESULTS AND DISCUSSION

Structures of farms where pulse was produced and all essential cultural practices were determined and presented in Table 1. Chemicals were sprayed 3.3, 2.4, 2.8 and 1 times on bean, lentil, irrigated chickpea and dryland chickpea farms, respectively. Irrigation operations were performed on average 7, 4.3 and 6.1 times in bean, lentil and irrigated chickpea farms. Land preparation and soil tillage were frequently accomplished by a Massey Ferguson 28,575 hp tractor along with moldboard plow, disc harrows, land leveler (for irrigated), and chisel (for dryland). The average farm sizes were in bean 2 ha, in lentil 0.7 ha, in irrigated chickpea 1.1 ha and in dryland chickpea 2.9 ha. About 79.6% of total land in chickpea production was dryland and only 20.4% was used as irrigated. Winter wheat, barley, cotton, corn, sorghum, tomato and alfalfa were grown along with pulse in the studied farms. The number of tractors per farm was 0.3 ha^{-1}. Other agronomic practices are shown in Table 1.

Table 1: Management practices for bean, lentil and irrigated and dryland chickpea

Practices/operations	Bean	Lentil	Irrigated chickpea	Dryland chickpea
Names of varieties	Derakhshan, Naze	Robat, Gachsaran	Jam, Kermanshahi, Karaj 12-60-31	Jam, Kermanshahi, Karaj 12-60-31
Land preparation tractor used: 285 MF 75 hp	Moldboard plow, Disc harrows, Land Leveller	Moldboard plow, Disc harrows, Land leveller	Moldboard plow, Disc harrows, Land leveller	Chisel
Land preparation period	April	February	February	October
Average tilling number	2.2	2.2	2.2	1.2
Planting period	May	March	March	November
Fertilization period (Before planting)	April	February	February	___
Fertilization period (Top dressing)	May	April	April	___
Average number of Fertilization	2.2	1.2	1.5	___
Irrigation period	May-September	March-June	March-July	___
Average number of irrigation	13.7	4.3	6.1	___
Spraying period	April-July	March-May	March-May	May
Average number of spraying	3.3	2.4	2.8	1
Harvesting period	August-September	May –June	June-July	May –June

Total energy used in different production processes for producing bean, lentil, irrigated chickpea and dryland chickpea are shown in tables 3, 4, 5 and 6. The main factors resulting in excessive energy use in irrigated chickpea were application of diesel fuel and irrigation water. However, the share of energy use of total energy for diesel and machinery were higher in dryland farms. But, the amount of energy used in different farming practices such as machinery, electricity and fertilizer in irrigated farms was higher than that of dryland farms.

Table 2: Energies consumed in bean farms

Energy	Quantity per unit area (ha)	Total energy equivalent (MJ)	Percentage of total energy input (%)
Input			
Human labor	525.90	1031.45	4.30
Machinery	24.45	1533.10	6.51
Diesel fuel	81.35	4086.20	17.26
Nitrogen	23.00	1735.60	7.33
Phosphate (P_2O5)	92.00	1202.40	5.10
Fungicide	0.50	90.95	0.38
Electricity	1400	5040.0	21.29
Water for irrigation	7000	7140.0	30.16
Seed	65.0	964.50	4.09
Outputs			
Bean grain yield	1217.50	18140.80	42.26
Bean straw yield	1982.50	24781.30	57.73
Total energy output		42922.00	

Table 3: Energies consumed in lentil farms

Energy	Quantity per unit area (ha)	Total energy equivalent (MJ)	Percentage of total energy input (%)
Input			
Human Labor	441.15	860.24	6.09
Machinery	20.15	1263.40	8.96
Diesel fuel	68.45	3438.24	24.36
Nitrogen	23.00	1735.60	12.29
Phosphate (P_2O5)	46.00	601.22	4.25
Potassium (K_2O)	25.00	278.75	1.98
Herbicides	1.00	238.00	1.68
Pesticide	2.00	202.40	1.44
Fungicide	0.50	90.95	0.64
Electricity	520	1872.00	13.27
Water for irrigation	2600	2652.00	18.79
Seed	60.00	882.00	6.25
Total energy input		14114.79	100.00
Outputs			
Bean grain yield	696.60	10240.02	40. 50
Lentil straw yield	1203.40	15042.50	59.50
Total energy output		25282.52	

Table 4: Energies consumed in irrigated chickpea f

Energy	Quantity per unit area (ha)	Total energy equivalent (MJ)	Percentage of total energy input (%)
Input			
Human Labor	434.55	847.37	5.37
Machinery	21.55	1351.18	8.57
Diesel fuel	72.85	3659.25	23.23
Nitrogen	23.00	1735.60	11.01
Phosphate (P_2O5)	46.00	601.22	3.81
Potassium (K_2O)	25.00	278.75	1.77
Herbicides	1.00	238.00	1.52
Pesticide	2.00	202.40	1.28
Fungicide	0.50	90.95	0.58
Electricity	700	2520.00	16.00

Table 5: Energies consumed in dryland chickpea farms

Energy	Quantity per unit area (ha)	Total energy equivalent (MJ)	Percentage of total energy input (%)
Input			
Human Labor	103.00	200.85	7.64
Machinery	9.00	564.30	21.45
Diesel fuel	29.00	1456.67	55.38
Nitrogen	-	-	-
Phosphate (P_2O5)	-	-	-
Potassium (K_2O)	-	-	-
Herbicides	1.00	187.80	7.14
Pesticide	-	-	-
Fungicide	-	-	-
Electricity	-	-	-
Water for irrigation	-	-	-
Total energy input		2630.12	100.00
Outputs			
Chickpea grain yield	144.70	2127.09	29.06
Chickpea straw yield	415.30	5191.25	70.94
Total energy output		7318.34	

The grain and straw yield data for bean, lentil, irrigated chickpea, and dryland chickpea farms have been computed and presented in Tables 3, 4, 5, and 6. Notably, the energy use efficiency in dryland chickpea was found to be nearly 2.4 times higher than that in irrigated chickpea. This disparity could be attributed to the utilization of lower input energy in dryland systems. The comparison underscores the influence of different cultivation practices and energy inputs on the overall energy use efficiency in chickpea production, demonstrating the potential benefits of more resource-efficient approaches in dryland conditions. The findings from our study reveal that energy was employed most efficiently in dryland chickpea cultivation, followed by bean, lentil, and irrigated chickpea. Notably, among irrigated production systems, bean farms exhibited the highest energy use efficiency. This observed high efficiency for beans is likely attributable to its superior output compared to both lentil and irrigated chickpea. These results highlight the nuanced variations in energy use efficiency among different pulse production systems, underscoring the importance of crop-specific factors in determining the overall effectiveness of energy utilization in agricultural practices.

Mean grain yield in dryland farms was 68.18% lower than that in irrigated farms. While chickpea yield was lower in dryland farms, the energy output-input ratio was higher. In another study in Iran. The total energy input consumed could be classified as direct (73.1%, 62.5%, 67.2% and 63.0%), indirect (26.9%, 37.5%, 32.8% and 37.0%), renewable (38.6%, 31.1%, 32.2% and 16.0%) and non-renewable (61.4%, 68.9%, 67.8% and 84.0%) energy in bean, lentil, irrigated chickpea and dryland chickpea, respectively (Table 7). The share of direct energy from total energy used in the studied crops was higher than indirect energy. Although, the share of direct energy in dryland chickpea farms (63.0%) was low, energy use efficiency was higher than other crops due to lack of irrigation and not using fertilizer. Total energy input in dryland chickpea systems were 83.3% lower than irrigated systems. In other words, total energy input needed in dryland chickpea system was 16.7% compared to the irrigated systems. The outcomes of our study revealed that the proportion of renewable energy from the total energy used in the investigated crops was lower compared to non-renewable energy. Specifically, while the share of renewable energy in bean was higher than in other crops, it remained outweighed by non-renewable sources. This underscores the need to actively reduce the reliance on non-renewable energy in order to achieve elevated levels of energy efficiency in agricultural production systems. A strategic shift towards a greater incorporation of renewable energy sources could contribute significantly to enhancing sustainability and mitigating the environmental impact associated with conventional energy inputs. The prevailing highly mechanized agricultural systems in many areas of Iran have led to a notable 10% increase in fuel consumption in recent years. Addressing this trend requires strategic measures aimed at reducing the consumption of diesel fuel and fertilizers, particularly Nitrogen. Significant impact in decreasing total energy consumption can be achieved through targeted efforts to economize diesel use. Implementing changes in tillage methods, harvest systems, and other agronomic operations stands out as a viable approach to enhance field energy efficiency, leading to not only economic benefits but also contributing to broader sustainability goals. Additionally, employing direct and local marketing strategies for crops not only enhances profitability for growers but also contributes to the reduction of energy required for their transportation. This approach aligns with sustainability practices by minimizing the carbon footprint associated with long-distance transportation, while simultaneously offering economic advantages to farmers through more direct and localized market channels. The integration of such marketing strategies can serve as a dual-purpose solution, fostering both economic viability and environmental sustainability in agricultural systems. Energy input and output, energy use efficiency, specific energy, energy productivity and net energy are summarized in Table 8. The highest energy use efficiency was 2.78 for dryland chickpea and the lowest was 1.21 for irrigated chickpea. Average energy productivity of bean, lentil, irrigated chickpea and dryland chickpea were 0.051, 0.049, 0.029 and 0.055 kg MJ^{-1}, respectively. This means that 0.051, 0.049, 0.029 and 0.055 outputs were obtained per unit energy in bean, lentil, irrigated chickpea and dryland chickpea, respectively. Development of low-input systems with using minimum rate of fossil energy while maintaining high output of food would help to reduce carbon dioxide emissions (Rathke and Diepenbrock, 2006). Enhancing our understanding of fossil energy usage in agricultural systems is essential for the development of agronomic practices that enable more efficient utilization of limited energy resources (Dalgaard et al., 2001). This knowledge is crucial for formulating sustainable and resource-efficient approaches to agriculture. By gaining insights into the specific dynamics of fossil energy use within agricultural processes, researchers and practitioners can work towards optimizing practices, reducing environmental impact, and ensuring a more resilient and sustainable agricultural system in the face of limited energy resources. It appears that the production of nitrogen fertilizer constitutes the most substantial component of energy consumption in the overall production of chemical fertilizers (McLaughlin et al., 2000). Nitrogen fertilizers play a critical role in enhancing soil fertility and promoting plant growth, but the energy-intensive process involved in their production underscores the importance of exploring alternative and more energy-efficient approaches in agricultural practices. Addressing the energy demands associated with nitrogen fertilizer production is a key consideration for achieving sustainability and resource efficiency in modern agriculture. Traditionally, legumes have been recognized as excellent sources of nitrogen in agriculture (Kinzig and Socolow, 1994). Utilizing crop rotations that include legumes, known for their ability to fix atmospheric nitrogen, can sustain production levels while diminishing dependence on energy-intensive mineral fertilizers (Rathke and Diepenbrock, 2006). This practice not only contributes to soil fertility through natural nitrogen fixation but also aligns with sustainable agricultural principles by reducing the need for resource-intensive synthetic fertilizers. Crop rotations with legumes thus represent an environmentally friendly and energy-efficient approach to maintaining agricultural productivity.

The production costs and gross product values are presented in Table 9, revealing that the total costs of production in bean were higher than in the other investigated crops. The study results indicate that the total production costs in bean, lentil, and irrigated chickpea were higher compared to dryland chickpea. This discrepancy can be attributed to the intensive use of fuel, fertilizer, water for irrigation, and electricity in irrigated chickpea cultivation. These findings underscore the economic dynamics associated with different pulse production systems, emphasizing the influence of input intensiveness on overall production costs.

Agriculture relies on substantial quantities of both locally available non-commercial energies, such as seeds, manure, and animal energy, as well as commercial energies, both directly and indirectly in the form of diesel, electricity, fertilizer, chemicals, irrigation water, and machinery. The efficient utilization of these inputs is crucial for achieving higher production levels and enhancing the economic stability, profitability, and competitiveness of agriculture sustainability (Singh et al., 2002). By optimizing the use of these diverse energy sources, agriculture can contribute to overall sustainability, balancing economic considerations with environmental and resource efficiency.

In recent decades, there has been a substantial increase in the consumption of fossil resources in the pursuit of higher agricultural yields. The extensive use of fossil energies poses threats to soil fertility and undermines the economic independence of farmers. Consequently, any positive change in energy consumption that leads to a reduction of reliance on fossil resources is poised to bring about positive effects in agricultural ecosystems. Such changes not only contribute to environmental sustainability but also support the economic resilience of farmers, fostering a more balanced and resource-efficient approach to agriculture.

4. Conclusions

The primary objective of this study was to conduct an energy input-output analysis of pulse production systems employed by Iranian farmers. This analysis aimed to comprehensively assess the energy dynamics involved in the cultivation of pulses, providing insights into the efficiency and sustainability of these agricultural practices. By scrutinizing the input and output energy components, the study sought to contribute valuable information for the development of informed and resource-efficient agricultural strategies in the context of pulse production in Iran.

The findings of the study reveal that diesel fuel, water for irrigation, machinery, and electricity were the predominant components of energy inputs in irrigated farms. The elevated consumption of diesel fuel is attributed to the intensive utilization of machinery for various operations, including soil preparation, cultural practices, harvest, and transportation. This insight into the major contributors to energy inputs underscores the significance of these resources in irrigated pulse production systems, highlighting areas where targeted interventions for efficiency and sustainability can be implemented.

The observed pattern may be influenced by the relatively small average size of pulse farms. However, the study's results suggest that water for irrigation was not utilized efficiently in the examined farms. This inefficiency appears to stem from the application of unsuitable irrigation methods by farmers, deviating from scientific principles. Addressing and improving irrigation practices in line with scientific guidelines could be a crucial avenue for enhancing water use efficiency in pulse farming, contributing to both environmental sustainability and the economic viability of agricultural operations.

Bean, lentil and irrigated chickpea consumed a total energy of 23666.7, 14114.8 and 15756.2 MJ ha^{-1}, which was mainly due to the application of diesel fuels, water for irrigation and electricity. Total energy input consumed in dryland chickpea was 2630.1 MJ ha^{-1}, which was mainly due to diesel fuel and machinery energy. With the exception of bean, the energy input in form of diesel fuels, water for irrigation and electricity had the first, secondary and third share within the total energy inputs in lentil and irrigated chickpea.

Energy use efficiency was 1.81 in the bean, 1.79 in the lentil, 1.21 in the irrigated chickpea and 2.78 in the dryland chickpea. Although net return per ha in dryland chickpea was less than irrigated one, energy efficiency and benefit to cost ratio in dryland were much higher than irrigated systems, meanwhile, there was at least a minimum crop production in areas with water deficiency. In terms of energy use efficiency, dryland chickpea farms reflected more than 1.5, 1.6 and 2.3 times the rate compared to irrigation investigated farms, subsequently a growing trend towards higher sustainability.

Achieving minimal production with high energy efficiency is increasingly vital in the current market scenario, where crop prices are rising rapidly, and predictions suggest further increases in the future. This becomes essential for governments and policymakers to prevent the development of a vulnerable food market and safeguard the well-being of low-income individuals. Striking a balance between efficient agricultural practices and food production is crucial for ensuring both economic stability and accessibility to essential food resources, especially for those with limited financial means.

Hence, there is a pressing need for the adoption of a new policy encouraging farmers to embrace energy-efficient practices that enhance crop yields without depleting natural resources. The outcomes of the current study emphasize that, among the studied crops, dryland chickpea exhibited the highest efficiency in terms of energy utilization. This underscores the potential benefits of promoting and incentivizing energy-efficient approaches in agriculture to ensure sustainable and resilient food production systems. A strategic shift towards such practices can contribute significantly to both agricultural productivity and the conservation of vital natural resources.

Dryland farming in Iran presents additional positive aspects, including the reduction of erosion through soil coverage and minimal or no consumption of biocides and synthetic fertilizers. These factors contribute to lower energy input requirements and establish more environmentally friendly production systems. Among the irrigated crops studied, bean demonstrated the highest efficiency in both energy and economic benefits. This suggests that promoting the cultivation of beans, particularly in irrigated systems, could offer a favorable balance between energy efficiency and economic returns, aligning with sustainable and environmentally conscious agricultural practices.

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