A Case Study of Energy Balance of Castor Bean Cultivation in Iran

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Abstract—**The production of biofuel from farm products has been promoted as a replacement for fossil fuels. Castor bean (Ricinus communis L.) is one of the best crops used to produce biodiesel. The first step toward the introduction and widespread cultivation of the crop is to investigate the energy balance and economic analysis for its production in the field. To do so, we studied the comparison of the energy balance sheet on three different planting dates and plant densities of Castor beans in the Urmia. All data, such as input and output, were converted to equal values of the consumed and produced energy, by using special formulas and indexes, after which the energy efficiency was calculated. The results of analysis of variance showed that the effect of different planting dates on energy output of biomass, grain, oil, protein yield, and their energy efficiency was significant. Energy efficiency of oil and protein yield was also affected by plant density per unit area. The interaction effect of planting date and plant density was also significant on biomass energy output and its efficiency, energy efficiency of oil, and protein yield. According to the results, in order to achieve maximum energy efficiency, it is suggested that the most desirable planting date is May 20 and the most suitable density of 16,000 plants per hectare in West Azerbaijan.**

Keywords—**biodiesel, castor, energy, planting date, plant density**

I. Introduction

Energy has become an essential commodity for humanity to sustain economic growth and maintain a high standard of living. Increasing industrialization has led to the depletion of nonrenewable resources, producing waste and causing environmental impacts due to air, soil, and water contamination [1]. Fossil fuels provide most of the energy that empowers modern society. However, widespread consumption of fossil fuels causes two crises: resource depletion and environmental degradation [2]. Recently reduction of fossil reserves, environmental issues, and problems resulting from the use of such fuels, persuaded scientists to find suitable alternative fuels. By increasing the population and following this with increasing energy consumption, the necessity to use fuels from plants and renewable sources is more evident. Currently, there is an increased use of renewables (e.g., biofuels) to replace the over-reliance on fossil fuels, as well as reduce resource consumption and waste production [3]. Bioenergy is an important alternative source of energy for Fossil fuels. The use of plant fuels as a renewable energy source that can be sustainable in the future helps to improve the environment by reducing greenhouse gases, and on the other hand, significant economic potential, a suitable alternative source for fossil fuels is considered [4]. To be sustainable, biofuels should not affect the quality, quantity, and use of water or soil, with unacceptable social consequences [5]. Consequently, a biofuel feedstock has to reduce the indirect land-use change, (e.g., the emission of more carbon dioxide as a consequence of the cultivation of new land in response to biofuel demand), which causes a subsequent deficit in food supply and an increase in food prices [6, 7].

Biodiesel is an alternative biofuel that can be extracted from vegetable oils. The energy produced from plants can be converted into liquid fuel and used in the existing transportation infrastructure, which is almost entirely run on fossil fuels (cars, buses, airplanes). These can be used directly or in combination with diesel fuel [8]. A study in the Philippines has shown that a minimum of 5% blend of biodiesel in all diesel products was mandated starting the year 2015 through biofuels act of 2006 and directed go up to 20% in the year 2030 [9]. In order to economically use an oilseed to produce biodiesel, the Energy Use Efficiency (EUE) must be positive. This is highly correlated with the energy input consumed in the production of the oilseed. Some analyses represent net positive energy balances in the production of biological energy [10–12]. But other studies indicate negative energy balance [13]. Most studies confirmed the relationship between biodiesel energy balances mainly with the crop production system [14].

Castor bean (Ricinus Communis L.) from Euphorbiaceae family as a good source of biofuel have different names in some countries (ricino, tartago, higuerilla, mamona) and present specific appearance [15]. It is used mainly to obtain castor oil from its seed. After the oil processes, the biomasic waste is used in different recovery processes to obtain energy, biodiesel, animal food, compost, paper, water retenders, etc. [16–18]. The seeds of Ricinus communis, which contain ricin, a water-

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soluble toxin, have limited uses for humans and animals [19]. However, when used as a raw material for oil production, it has comparative advantages over other seeds. The plantation cost of Ricinus communis is significantly less than other plants such as soybean and rapeseed. Ricinus communis plant is also drought tolerant, pest-resistant, require less artificial care, and biomass could be harvested three times a year. Therefore, Ricinus communis seed is a sustainable source and an attractive feedstock for bio-oil production. Castor bean contains 50 percent oil [20, 21] which is considerably better than those of soybean (19%) and cotton seed oil (20%) [22]. There are already published studies on biodiesel production using Ricinus communis seeds [23–25]. Because of the low expectations of this plant to the fertility and tissue of the soil, its culture is appropriate on the marginal lands for desertification and soil erosion. In addition, castor crop can be put into the rotation plan to be used in agricultural ecosystems. Despite the production of fuel and other benefits of this plant, especially in dry and semi-dry weather of Iran, culture of this unfortunately is forgotten in recent decades. So, no accurate statistics are available on the area under castor cultivation. Investigation the inputs on the production is an important strategy for optimizing energy consumption [26]. By examining the most influential indicators and the possibility of replacing them with other factors, observation of all the economic and technical aspects, it can be optimized for the energy consumption pattern in agricultural products. The use of varieties with higher photosynthetic efficiency and more, higher design of agricultural machinery, and the use of more effective techniques in the distributing of fertilizers and pesticides including proposed research solutions are reduced to energy input. The relationship between input and output energy in the field depends on the type of product, soil type, tillage operation, type and amount of fertilizers, harvesting operation, and finally yield levels [27]. The present study was carried out by measuring and investigating the energy balance of castor plant production as a suitable source of biodiesel in Urmia, Iran. The rest of this paper is organized as follows. Section II introduces methods and materials in this experiment consist of site and experiment characteristics, measurement and analyze of data. The results of data analysis are demonstrated in Section III. Finally, Section IV concluded this paper.

II. Methods and Materials

A. Site Description and Climatic Characteristics

This experiment was conducted in agricultural research station in West Azerbaijan, Urmia, Iran (45°2'7" E longitude and 36°47'87" N latitude) in 2019 the growing season. The soil of the region has a clayey silty texture according to the result of soil decomposition. The average rainfall, temperature and average relative humidity in the crop season are given in Table I based on the statistics published by the Meteorological Organization.

TABLE I. Meteorological Statistics in the Year 2019 in Urmia

Months	Temperature (C)	Relative humidity (%)	Rainfall (mm)	Sunny hours	Evaporation
March	12.9	48.3	3.4	238.9	99.9
April	15.3	49.6	24.5	273.1	122.4
May	17.7	50	0	372.9	288.6
June	23.9	49.6	10.9	364.9	283.8
July	25.4	44.9	0	348.3	305
August	21.4	51.6	0.2	280.7	218.4
September	15	59.6	0.5	268.3	99

B. Field Preparation and Treatments Application

In order to evaluate energy efficiency in castor bean, an experiment was conducted as a factorial in form of a randomized complete block design with three replications. The experimental factors included three planting dates (5, 20 May, and 5 June) and three planting densities (25,000, 20,000, and 16,000 plants per hectare). The seedbed preparation operation, after plowing with a reversible plow, was done by leveling the soil and softening the soil. When preparing the soil, according to the results of soil decomposition, the necessary amounts of phosphorus, potassium and nitrogen fertilizers (NPK 100, 25, 45 $kg.ha^{-1}$ respectively) from fertilizer sources of urea, ammonium phosphate and potassium sulfate were distributed to the soil (urea was used in two installments). After planting in different dates and densities with amount of seeds (12, 9.6, 7.8 $kg.ha^{-1}$), Thinning and Irrigation (1,920, 2,400, and 3,000 m^3) and weeding were performed. The seed used was the local cultivar of Urmia, which was prepared from the Agricultural and Natural Resources Research Center of West Azerbaijan. Total manpower used was 73, 91 and 114 hours in this study.

C. Measurements

All data used in this research work are obtained from castor cultivation after examining comprehensive resources in Urmia County (West Azerbaijan, Iran). To estimate the energy balance at different planting dates and densities, the amount of each of the factors and inputs used and the outputs obtained in each of the treatments were converted into equivalent energy levels. Kjeldahl-device was used to measure the energy of castor seed protein. The total energy of the factors and inputs used was calculated according to the amount of inputs used and agricultural operations in the treatments. The energy required to produce, depreciate and maintain machinery and transfer equipment to the farm was also considered. These energies formed the input energy of the ecosystem. The output energy was calculated by multiplying the grain yield, biomass yield, oil and protein percentage by the amount of energy per grain. Finally, energy efficiency was obtained from outside the amount of output energy to the amount of input energy. The obtained data were analyzed by variance and the means were compared with Duncan's multiple range test. The data were analyzed using the Statistical Analysis System (SAS 9.1) and means were compared using Duncan test at $p \leq 0.05$ probability. According to the above discussion, Table II is provided.

TABLE II. ENERGY EQUIVALENT OF INPUTS AND OUTPUTS IN CASTOR PRODUCTION

	Type	Unit	Energy equivalent (kcal unit-1)	Refs.
Human labor	Labor & Driver	h	526	[28]
Seed		kg	4872	[28]
Fertilizer	N	kg	11249	[28]
	P		3773	[28]
	K		2216	[28]
Irrigation		m^3	150	[13]
Diesel fuel	Agricultural operations & Transfer to farm	L	9219	[28]
Build & depreciation of farm machinery	Tractor	kg	22358	[12]
	Moldboard plow		14976	[28]
	Rotary disc		14976	[28]
	Fertilizer spreader		14976	[28]
	Drill		14976	[28]
Maintenance of farm machinery	Tractor	kg	115	[10]
	Moldboard plow		232	[10]
	Rotary disc		131	[10]
	Fertilizer spreader		131	[10]
	Drill		131	[10]
Biomass		kg	4204	[28]
Oil		kg	9200	
Protein		kg	3000	

III. RESULTS

According to Table III, the amount of energy consumed in different planting treatments increased with increasing plant density per unit area. The highest input energy was at a density of 25,000 plants per hectare. The lowest input energy was related to plant density of 16,000 plants per hectare. Fertilizers are the most energy consumed at the inputs. Most of the energy of fertilizers was related to nitrogen fertilizer. The high energy consumption required for the production of chemical fertilizers on the one hand and the increase in environmental problems and consequently their use on the other hand, shows the importance of organic resources such as composts [26, 29]. Similarly, in the alkaline soil of the country, which has difficulty stabilizing phosphorus, vermicomposts can help release phosphorus from hardened phosphor layers to meet plant's need [30]. After fertilizers, fuel and irrigation have the highest energy consumption of the total input energy, respectively. High energy consumption in relation to fuel shows that it is very important to consider mass production of biodiesel plants. By using biodiesel in agricultural machinery, the actual energy and real cost per liter of biodiesel produced can be significantly reduced. On the other hand, the use of intensive irrigation systems that significantly reduce the amount of water can be effective in reducing energy consumption, because the castor plant needs little water and is able to withstand drought. Although the amount of seed and labor do not account for a large amount of energy consumption, production costs increase due to the amount of grain and manual harvest. This plant also contains oleic acid and other alkaloids, which can be allergenic and toxic and can cause problems for workers. Therefore, it is recommended that breeding measures be initiated to produce dwarf species from the local population or ecologically compatible with global dwarf species grown domestically.

The results of analysis of variance (Table IV) showed that the effect of different planting dates on energy output of biomass, grain, oil, protein yield, and their energy efficiency was significant. Energy efficiency of oil and protein yield was also affected by plant density per unit area. The interaction effect of planting date and plant density was also significant on biomass energy output and its efficiency, energy efficiency of oil and protein yield. Comparison of means (Table V) showed that the highest energy output of grain, oil and protein yield were related to the third planting date (June 5) and the lowest were related to the first planting date (May 5). Later planting causes a suitable temperature for the plant during the vegetative and reproductive period, resulting in increased photosynthetic efficiency, followed by increased transfer of photosynthetic materials and their storage in the seeds, and increased yield. Also, higher temperatures and more radiation at this planting date, which affects the seed filling, increase its yield and energy. The high energy yield of oil and protein in late sowing is also due to the fact that in early sowing, grain yield decreases due to unsuitable thermal conditions. Because the yield of oil and protein depend on two factors of grain yield and the percentage of oil and grain protein, the energy of both yields affected by these two factors was highest on the third planting date. Grain energy efficiency increased from 4.12 on the first planting date to 8.34 on the third planting date by increasing the grain energy output relative to the input consumption. Energy efficiency or Energy ratio is an indicator that can be used to compare different systems. When comparing the energy efficiency of castor oil and other oilseeds used for biodiesel production, the potential for biodiesel production can be demonstrated. Energy utilization efficiency was produced only for soybeans produced 1.60, 5.41, and 1.03 after considering biomass and measured in rapeseed [31]. This plant shows great potential for energy development because it produces a large volume of biomass and the biomass produced can be used to produce bioethanol. Since the present study was conducted for the first time in West Azerbaijan, there is no data to compare this system with other systems. However, in a similar study conducted in the city of Varamin (Tehran, Iran), the energy efficiency was calculated to be 144.66 counting the produced biomass, and 3.81 for the produced seeds only [28]. In the research carried out in Brazil, the energy productivity was reported to be 117 0.02 and 0.14 $kg.MJ^{-1}$ in traditional and mechanized farming systems respectively [17].

In this study conducted in Brazil, only the energy of the seeds was calculated. Moreover, the yield of native cultivars used in other countries was very low compared to the local population of Iran (850 and 1,500 kg/ha). This indicates the need to improve existing populations to facilitate mechanized cultivation [28]. Comparison of the means of interaction (Table V) showed that the highest biomass energy output and its efficiency, energy efficiency of oil and protein yield was related to the treatment combination of the second planting date and density of 16,000 plants per hectare (60–100 cm). Biomass is directly related to photosynthesis in plants. At low plant densities per unit area, single plant biomass increases due to less competition of plants for light, water, and nutrient uptake. Also, planting at the right date causes the plant to have sufficient vegetative growth at the time when there is maximum solar radiation and to be able to make maximum use of environmental factors. As a result of increasing photosynthesis, biomass also increases. The minimum biomass energy output and its efficiency were obtained from the combination of the first planting date and the density of 16,000 plants per hectare (60–100 cm). This indicates a greater effect of planting date than plant density on this trait, which is not significant in different plant densities. The lowest energy efficiency of oil and protein yield was obtained from the combination of the third planting date and a density of 25,000 plants per hectare (40–100 cm) (Fig. 1).

TABLE III. ENERGY EQUIVALENT OF INPUTS AND OUTPUTS IN CASTOR PRODUCTION

		Fertilizer (kg)					**Build depreciation of farm machinery (kg)**					**Maintenance of farm machinery (kg)**							
Treatment number	Treatment	N	P	K	Irrigation (m^3)	Human labor (h)	Tractor	Moldboard plow	Rotary disc	Fertilizer spreader	Drill	Tractor	Moldboard plow	Rotary disc	Fertilizer spreader	Drill	Diesel fuel (L) (h)	Seed (kg)	Total (kcal)
1	a1*b2	1124900	94325	99720	450000	59964	157.26	8.15	36.72	9.17	35.53	0.81	0.13	0.33	0.08	0.31	2393.2	58464	1890015.59
2	a1*b2	1124900	94325	99720	360000	47866	157.26	8.15	37.62	9.17	35.53	0.81	0.13	0.33	0.08	0.31	2393.2	46771.2	1776224.79
3	a1*b3	1124900	94325	99720	288000	38398	157.26	8.15	37.62	9.17	35.53	0.81	0.13	0.33	0.08	0.31	2393.2	37416.96	1685402.55
4	a2*b1	1124900	94325	99720	450000	59964	157.26	8.15	37.62	9.17	35.53	0.81	0.13	0.33	0.08	0.31	2393.2	58464	1890015.59
5	a2*b2	1124900	94325	99720	360000	47866	157.26	8.15	37.62	9.17	35.53	0.81	0.13	0.33	0.08	0.31	2393.2	46771.2	1776224.79
6	a2*b3	1124900	94325	99720	288000	38398	157.26	8.15	37.62	9.17	35.53	0.81	0.13	0.33	0.08	0.31	2393.2	37416.96	1685402.55
7	a3*b1	1124900	94325	99720	450000	59964	157.26	8.15	37.62	9.17	35.53	0.81	0.13	0.33	0.08	0.31	2393.2	58464	1890015.59
8	a3*b2	1124900	94325	99720	360000	47866	157.26	8.15	37.62	9.17	35.53	0.81	0.13	0.33	0.08	0.31	2393.2	46771.2	1776224.79
9	a3*b3	1124900	94325	99720	288000	38398	157.26	8.15	37.62	9.17	35.53	0.81	0.13	0.33	0.08	0.31	2393.2	37416.96	1685402.55

a1, a2 and a3 were planting dates at 5, 20 May, and 5 June respectively. b1, b2 and b3 were planting densities 25,000, 20,000 and 16,000 plants/ha respectively.

TABLE IV. ANALYSIS OF VARIANCE (MEAN SQUARES) OF THE FOLLOWING TRAITS IN CASTOR

Source of variation	**Degree freedom**	**Energy output of biomass yield (kcal)**	**Energy output of grain yield (kcal)**	**Energy output of oil yield (kcal)**	**Energy output of protein yield (kcal)**	**Energy efficiency of biomass**	**Energy efficiency of grain**	**Energy efficiency of oil**	**Energy efficiency of protein**
Repetition	2	3.20	1.87	1.56	1.82	100.5	5.67	0.0001	0.000003
A: Planting date	2	1.53^{**}	1.27^{**}	3.07^{**}	3.33^{**}	514.5^{**}	40.05^{**}	0.003^{**}	0.000037^{**}
B: Planting density	2	1.26^{ns}	5.18^{ns}	39354^{ns}	4.3^{ns}	26.3^{ns}	0.04^{ns}	0.004^{**}	0.000053^{**}
A*B	4	3.82^{*}	26638^{ns}	2.52^{ns}	2.06^{ns}	136.98^{*}	0.06^{ns}	0.001^{**}	0.000009^{**}
Error	16	1.23	2.62	2.1	2.45	38.85	0.71	0.00009	0.000001
Coefficient variation (%)		16.72	14.73	18.75	19.18	16.74	13.74	4.95	6.13

^{ns}: Not Significant, **: Significant at 1% level, *: Significant at 5% level

TABLE V. COMPARISON OF THE MEANS OF INTERACTION EFFECTS ON THE FOLLOWING TRAITS IN CASTOR

Treatment number	Treatments freedom	Energy output of biomass yield (kcal)	Energy output of grain yield (kcal)	Energy output of oil yield (kcal)	Energy output of protein yield (kcal)	Energy efficiency of biomass	Energy efficiency of grain	Energy efficiency of oil	Energy efficiency of protein
1	a1b1	61289366 ^{CD}	7866672D ^{EF}	6719330 ^{BC}	700514438 ^{BC}	32.42 ^{C}	4.16 ^{C}	0.215 ^{A}	0.022 ^{ABC}
2	a1b2	67728668 ^{BC}	7536755 ^{EF}	5808049 ^{BC}	615283783 ^{BC}	38.13 ^{BC}	4.24 ^{C}	0.210 ^{A}	0.022 ^{ABC}
3	a1b3	45127788 ^{D}	6703507 ^{F}	5084136 ^{C}	543454918 ^{C}	26.77 ^{C}	3.97 ^{C}	0.220 ^{A}	0.023 ^{AB}
4	a2b1	71941543 ^{ABC}	11558372 ^{BC}	7732364 ^{ABC}	802987832 ^{ABC}	38.06 ^{BC}	6.11 ^{B}	0.171 ^{C}	0.017 ^{D}
5	a2b2	82494772 ^{AB}	10738312 ^{CD}	7997077 ^{AB}	840913019 ^{ABC}	46.44 ^{AB}	6.04 ^{B}	0.203 ^{AB}	0.021 ^{BC}
6	a2b3	89871701 ^{A}	9959903 ^{CDE}	7624831 ^{ABC}	830242472 ^{ABC}	53.32 ^{A}	5.90 ^{B}	0.221 ^{A}	0.024 ^{A}
7	a3b1	69237723 ^{ABC}	15968141 ^{A}	8350300 ^{AB}	898020168 ^{AB}	36.63 ^{BC}	8.44 ^{A}	0.134 ^{D}	0.014 ^{E}
8	a3b2	58014305 ^{CD}	14474873 ^{AB}	10135603 ^{A}	1067786723 ^{A}	32.66 ^{C}	8.14 ^{A}	0.191 ^{B}	0.020 ^{C}
9	a3b3	51540056 ^{CD}	14194957 ^{AB}	10206207 ^{A}	1048061302 ^{A}	30.58 ^{C}	8.42 ^{A}	0.207 ^{AB}	0.021 ^{BC}

The same letters in each column show non-significant differences at $p \leq 0.05$, analyzed by Duncan's multiple range test.

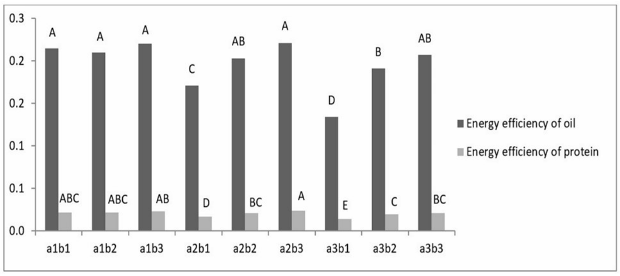

Figure 1. Comparison of the means of interaction effects on energy efficiency of oil and protein in castor a1, a2 and a3 were planting dates at 5, 20 May and 5 June respectively. b1, b2, and b3 were planting densities 25,000, 20,000, and 16,000 plants/ha respectively.

IV. DISCUSSION

Due to the unique benefits of castor oil and high energy efficiency in its production, the development of cultivation of this plant as a raw material for biodiesel production can be an effective step in the use of renewable fuels. On the other hand, registration of local cultivars, research for the most suitable date and plant density, production of dwarfs and facilitating the design of required machinery and gradual replacement of chemical fertilizers with organic matter and the use of high-yield cultivars are important strategies for Development and expansion of castor cultivation in accordance with ecological principles in Iran.

V. CONCLUSION

According to the result, castor is an affordable source for biodiesel production if upgrading happens for biodiesel production systems by more and more research. In order to achieve a desirable yield and in order to increase energy efficiency, the distribution of plants per unit area and determining an optimal density and selecting the best planting date are among the factors that should be paid special attention in crop management. Therefore, considering the results of the experiment and the purpose of castor cultivation, in order to achieve maximum energy efficiency, it is suggested that the most desirable planting date is May 20 and the most suitable density of 16,000 plants per hectare in West Azerbaijan.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Sharara Jahannavard conducted the field experiments and performed the laboratory work and collected the data. Abdullah Hassanzadeh analyzed the data statistically. Preparation and writing of the manuscript was done by Sharara Jahannavard, and Abdullah Hassanzadeh edited the manuscript. All authors approved the final version.

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