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A Case Study of Energy Balance and Economic Analysis of Castor Cultivation in Iran

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***Abstract*—Castor bean (*Ricinus communis* L.) with 50 percent of oil content and high- quality, is one of the best crop used to produce biodiesel. The first step toward 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, energy input (include renewable and nonrenewable) and output were calculated during a two years field experiment (2012-2014) in Tehran-Iran. Energy indicators were also assessed. Result showed Indirect and non-renewable sources of energy with 59.68 and 80.86 percent of 11245.64 Mega Joule energy consumption respectively, and comprise the major part of the consumable energy in castor bean cultivation. Moreover, fertilizers and pesticides considered as the most energy inputs, i.e. 55.26 percent of the total consumable energy. Fuels follow that with 21.28 percent and formed a large part of the total consumable energy. Energy use efficiency in Castor seed production was calculated to be 3.81, which is a considerable amount when compared with other crops used to produce biodiesel. According to economic analysis result, castor is an affordable source for biodiesel production. But the height of this plant is a major problem to expand the cost efficient and mechanized system of castor production. Therefore, breeding of the current local ecotypes is recommended.**

***Index Terms*—biodiesel, energy use efficiency, net energy gain, energy efficiency and bioethanol**

I. INTRODUCTION

Recently concern over diminishing resources of fossil fuels, environmental issues and increased emissions resulting from the use of such fuels, encouraged scientists to conduct extensive researches to find suitable alternative fuels. Biodiesel is an alternative biofuel which can be extracted from vegetable oil or animal fat. Processed oilseeds can be used directly or in combination with diesel fuel. In order to economically use an oilseed to produce biodiesel, the obtained energy must be positive in comparison with the energy consumed to produce the oilseed. This concept is expressed by an index called Energy Use Efficiency (EUE). This balance is highly correlated with the energy input consumed in the production of the oilseed [1]-[3]. Castor bean (*Ricinus Communis* L.) is a member of *Euphorbiaceae* family which be considered as a good source of biofuel. Castor seeds contain 50 percent oil, which is considerably better than those of soybean (19%) and cotton seed oil (20%) [4]. since the crop could resist the unfavorable soil conditions such as poor soil texture and low fertility, it can be cultivated in marginal lands to prevent desertification and soil erosion [3], [5]. Having arid or semi-arid climates, most parts of Iran are candidate to cultivating this crop. Therefore, one can consider fuel production and other benefits of these areas while protecting them against soil erosion. In addition, castor crop can be put into the rotation plan to be used in agricultural ecosystems. Despite the fact that Iranian traditional farmers are familiar with this oilseed crop and its cultivation unfortunately it was forgotten during the last two decades; therefore, no accurate statistics are available on the area under castor cultivation.

Since the agriculture industry is both energy consumer and energy producer, investigation of the impact of increased inputs on the production is an important strategy to optimize energy consumption [6], [7]. The first step towards this is to examine and assess the indicators provided by regional studies. The question of what factors have the greatest effect on the amount of indicators and how, along with considering the possibility of replacing them with the other factors as well as economic and technical considerations, can eventually lead to the optimization of energy consumption pattern in agricultural products. The solutions suggested by various researches to reduce the energy input are: designing better agricultural machinery, employing more effective techniques of distributing fertilizers and pesticides, and using varieties with higher photosynthetic efficiency [8], [9].

Energy consumption in agricultural products includes two parts: energy consumption inside and outside the farm. Consumed energy in the farm can be divided into two categories: direct and indirect consumption. The fuel required by tractors and other machineries needed for all the practices including land preparation, cultivation, and harvesting, the electricity used in irrigation pumps and other equipment, and the fuel consumed to heat installations and dry products are all the examples of direct use of energy. Indirect use of energy includes: the energy consumed to make farm equipment and

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infrastructure, the energy needed to manufacture agricultural devices and machineries, the energy consumed to produce agrochemical, and so on. Energy consumption outside the farm includes product processing and transportation. The relationship between the energy input and the energy output in the cropping system varies according to type of the product, soil type, tillage operation, the kind and amount of fertilizers, harvesting operation, and finally yield levels [10].

The present study deals with measuring and investigating the energy balance of castor oil plant production as a suitable source of biodiesel in Tehran province, Iran.

II. MATERIALS AND METHODS

All data used in this research work are obtained from two consecutive years of castor cultivation after examining comprehensive resources in Varamin County (Tehran, Iran). According to these data, following indices for energy balance investigation were calculated.

A. *Energy Ratio or Energy Use Efficiency (ER)*

This indicator shows the relationship between energy input and energy output, being defined as follows [11]-[13]:

$$\text{Energy ratio} = \text{output energy } (\text{MJ ha}^{-1}) / \text{ input energy } (\text{MJ ha}^{-1}) \quad (1)$$

As in Eq. (1), the numerator and denominator are of the same dimension, so the energy ratio is a dimensionless indicator. It can thus be used to compare every type of products.

B. *Energy Productivity (EP)*

Energy productivity is the deployment of the most appropriate strategy in order to use energy resources from production to consumption, and is defined as follows [12]:

$$\text{Energy productivity} = \text{yield of the product } (\text{Kg ha}^{-1}) / \text{ input energy } (\text{MJ ha}^{-1}) \quad (2)$$

Measure of energy productivity is kilogram per mega joule. It is used to compare two identical products in different production systems, indicating the efficiency of each system [12], [13]. Moreover, energy productivity and the other special energy indicators are used to show the amount of energy required to produce each unit of the product.

C. *Net Energy Gain (NEG3)*

The difference between the input and output energy is shown as follows [11]:

$$\text{Net energy gain} = \text{output energy} - \text{input energy} \quad (3)$$

Net energy gain refers to potential development of energy which depends on farming techniques and the way, the farm is managed.

D. *Human Equivalent Energy*

Apart from irrigation, thinning and harvesting practices which were done by human, the other farming operations to cultivate castor are mechanized. Non-mechanized harvesting includes a two-stage raceme picking operation which is carried out by four people per ha within 10 hours. Also, in each hectare, the product is weeded and thinned by three people within 8 hours. Here, manpower is provided to complete the cultivation process, irrigation and the other ancillary activities. The energy consumed by the tractor driver is also included in this part. Total manpower used was 114 h in this study.

E. *Seed, Pesticide and Fertilizer Equivalent Energy*

By considering the amount of seeds (12 kg.ha^{-1}), herbicide (Treflan, 3 kg.ha^{-1}) , pesticide (Diazinon, 1 kg.ha^{-1}) and fertilizers (NPK and S, 100, 25, 45 and 40 kg.ha^{-1} respectively) which are used in the castor field as well as the equivalent energy of each case, the total energy of these inputs is measured. The output energy of castor bean seeds is assessed based on its chemical composition which averagely contains 50 percent oil and 16 percent protein [14], [15]. Furthermore, considering castor's high resistance to pests and diseases which results from the chemical composition of seeds and leaves, herbicides constitutes the major part of chemicals used in castor farms. In addition, weed management is of greater importance during initial stages of the plant's growth because of its final size and canopy. Therefore, it is recommended that pre-planting herbicides be used.

F. *Irrigation Equivalent Energy*

Castor resistance to drought and its low irrigation requirement is the most important feature of castor. Depending on the climate, this crop is reported to need 2000-2500 $\text{m}^3.\text{ha}^{-1}$ [5]. Due to the lack of accurate measurement of this crop's water requirement and the geographical situation of Varamin County which is located in an arid region, castor water requirement was estimated to be 3000 m^3 in the present study. In estimation of irrigation equivalent energy of production, depreciation and water pump fuel were also taken into account.

G. *The Equivalent Energy Consumed in Agricultural Machinery and Devices*

The energy used in this case include the energy required to produce and depreciate machinery and equipment, the energy required to transfer equipment to the farm, the fuel equivalent energy, and maintenance equivalent energy. The Eq. (4) has been suggested in order to calculate the energy of production and depreciation [16].

$$M_{pe} = GM_pT/W \quad (4)$$

M_{Pe} shows the energy of machine's production and depreciation in Mega joule (MJ), and G shows the machine's weight in kilogram (kg). M_p , T and W show the production energy in (MJ.kg^{-1}), hours of operation and the economic life of the machine respectively.

Depreciation refers to a reduction in the economic value of the machine over time. In this definition, the role of inflation is partially overlooked which may cause flaws in the form of difference between the actual current value of the machine and the value obtained from it. Determining the exact life of a machine is very complicated. However, the useful life of the tractors and the other agricultural equipment can be estimated by considering numerous factors such as quality of manufacture, soil type, kind of the product, the climate, etc. (Table I). In sum, one can calculate the equivalent energy and the deprecation of machinery through Eq. (4) and the measurement of equivalent energy for each unit.

TABLE I. FARM MACHINERY USED IN CASTOR PRODUCTION

Name of machine	Weight(kg)	Economic Life(h)
Tractor	2800	10000
Moldboard plow	325	2500
Rotary disc	1000	2500
Fertilizer spreader	117	1200
Drill	680	1200
Sprayer	150	1500

In order to prepare the seedbed, the land was plowed by three-bottom moldboard plow. Disc grinding was then carried out twice by 28- blade disc. Cultivation, spraying and fertilization were carried out by grain drills, tractor mounted boom spray and centrifugal fertilizer respectively. The consumable fuel was determined to be 8.9 liters per hour for all operations with regard to Ferguson 4 cylinder tractors (MF-285) and Ferguson 4 cylinder tractors (MF-399), which are commonly used in the region [17]. The average fuel required to transfer machinery to the farm has also been added to the above-mentioned amount.

According to the above discussion in sections D, E, F and G Table II is provided.

TABLE II. ENERGY EQUIVALENT OF INPUTS USED IN CASTOR PRODUCTION

Input		Unit	Energy equivalent (MJ unit_1)	Refs.
Human labor	Labor & Driver	h	2.20	18
Seed		kg	20.4	18
Fertilizer, Herbicide & Pesticide	N	kg	47.10	6
	P		15.80	6
	K		9.28	6
	S		6.30	19
	Treflan		85	20
	Diazinon		184.70	18
Irrigation		m^3	0.63	10
Diesel fuel	Agricultural operations & Transfer to farm	L	38.60	18
Build & Depreciation of farm machinery	Tractor	kg	93.61	9
	Moldboard plow		62.70	26
	Rotary disc		62.70	26
	Sprayer		62.70	26
	Fertilizer spreader		62.70	26
	Drill		62.70	26
Maintenance of farm machinery	Tractor	kg	0.48	7
	Moldboard plow		0.97	7
	Rotary disc		0.55	7
	Sprayer		0.37	7
	Fertilizer spreader		0.55	7
	Drill		0.55	7

H. *Product Equivalent Energy*

With the density of 25000 plants/ha, the average yield will be 2100 kg of grain and 90 tons biomass/ha. Since the produced biomass has the capability to turn into bioethanol, the seed yield and seed yield +biomass are considered separately in the output energy and the other indicators. The equivalent energy was considered to be 20.4 MJ [15] and 17.6 MJ [18] per kilogram of seeds harvested and per kilogram of biomass respectively. Therefore, energy productivity and energy net gain were measured using relations 1, 2 and 3.

I. *Cost of Production*

Production costs are including planting, cultivating, harvesting, transfer and peeling [19]. Peeling machine capacity is 50 kg seed per hour and its power consumption is 493 watts per hour. The costs are calculated based on fuel prices in the country, 0.15 and 0.07 $ per liter of gasoline without and with subsidy respectively. Production cost, cost per kg of seed and profits are calculated in three different modes. In the first and second mode used machinery is belong to farmer and all operations are carried out by family labor force (which is common in Iran). In this case, the cost of fuel and consumables were estimated, with and without subsidy in mode 1 and 2 respectively. In the third mode all calculations were estimated by assuming the services provided by the Agricultural Service Centers. In all modes, the land belongs to the farmer is assumed, and the rental rates are not calculated. As regard that insuring of plant is not common in Iran, this part of the costs has not been calculated. In order to more accurate calculation, check cultivation program for several years of farm and adding interest rate of fixed capital to total cost is recommended [19]. But in this research due to narrow cultivation of castor in Iran, the interest rate was not calculated in any modes mentioned in above.

III. RESULTS AND DISCUSSION

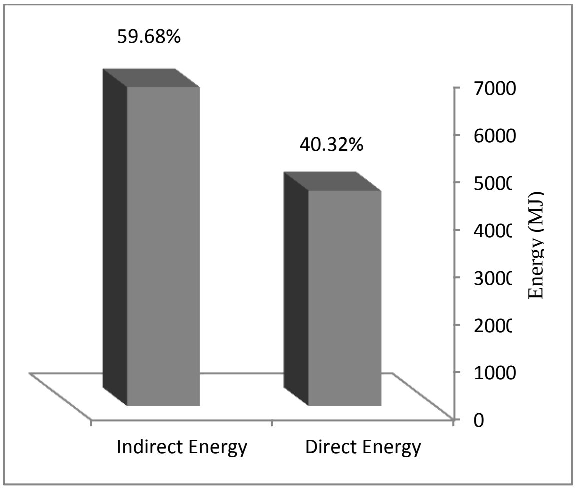

Figure 1. The consumable energy classification in castor production according to type of use.

Fig. 1 and Fig. 2 show consumable energy classification (direct, indirect, renewable and non-renewable sources) in castor production. Direct energy includes fuel, human force and irrigation while indirect energy includes other inputs such as fertilizers, pesticides and seeds. Also human force and irrigation could be classified as the renewable energy and fuel and chemicals are examples of the non-renewable energy.

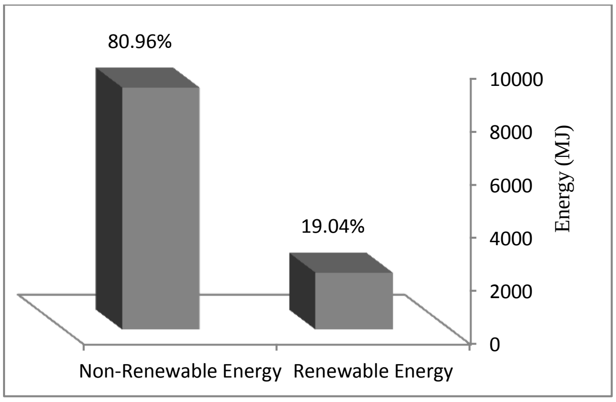

Figure 2. The consumable energy classification in castor production according to the renewability.

According to the figures, most energy used in this production system is indirect and non-renewable.

As is shown in Table III, fertilizers and pesticides, which fall into the category of indirect non-renewable energies, constitute 55.26 percent, i.e. the major consumable energy among the inputs. A large portion of the energy needed in this part is related to nitrogen fertilizer with 41.88 percent. High energy consumption needed for production of chemical fertilizers on one hand and increased environmental problems resulting their utilization on the other hand, is indicative of the importance of organic resources such as composts [1], [6], [9], [12]. Similarly, in the country's alkaline soil which is having problems with phosphorous fixation, vermicomposts and sulfur can help release phosphorus from hardened phosphorous layers to meet the plant's need [20], [21].

Following fertilizers and pesticides, the fuels and irrigation are the highest energy consumers with 21.28 and 16.81 percent of the total input energy respectively "Fig. 3". Both are non-renewable and fall into the category of direct energies. The high energy consumption in relation to fuels indicates that it is very important to consider mass production of efficient biodiesel production plants. Using biodiesels in farming machinery, one can substantially reduce the energy and the actual cost of each liter of produced biodiesel. On the other hand, using intensive irrigation systems which reduce water consumption to a considerable degree can play an effective role in reducing energy consumption, because castor plant needs little water and is able to withstand the drought.

Although the labor force does not constitute a high percentage of energy consumption, production costs are increased due to the products being harvested manually. Containing Ricin oleic acid and the other alkaloids, this plant can also be allergen and toxic and cause problems for workers. Therefore, it is recommended that the breeding actions be started to produce dwarf varieties from local populations or to ecologically adapt the world dwarf varieties to be cultivated inside the country.

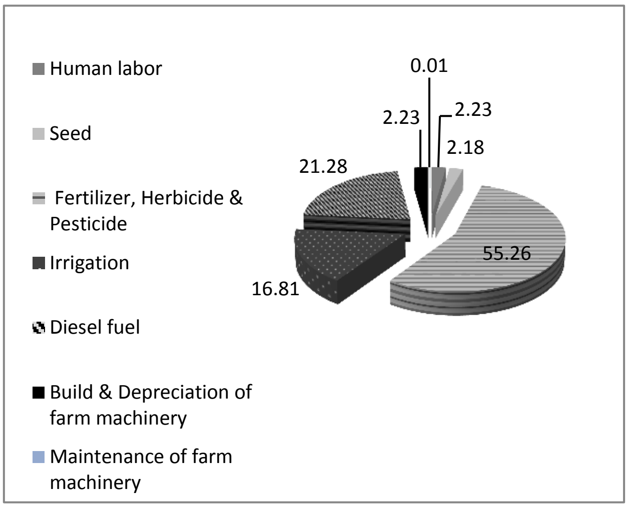

Figure 3. The Input ratios of consumable energy in castor production

The energy use efficiency of this cultivation system was calculated to be 144.66 counting the produced biomass, and 3.81 for the produced seed only. As mentioned earlier, the energy ratio or energy use efficiency is an indicator which may be used to compare different systems. Castor can be shown to have the potential to produce biodiesel when energy use efficiency is compared in castor and the other oil plants used to produce biodiesel. The Energy use efficiency was measured to be 1.60, 5.41 and 1.03 for produced soybeans only, after considering the produced biomass and in rapeseed respectively [22], [23]. The plant demonstrates a great potential for energy development since it produces large volumes of biomass and the produced biomass is usable for bioethanol production [24]. In the present study, the net energy gain was 1615594.36 and 31594.36 MJ respectively when calculated with and without the produced biomass. The net energy gain indicates the advantage that castor plant is superior to other oil plants in bioenergy production.

Energy efficiency in castor cultivation is 8.19 $kg.MJ^{-1}$ with the produced biomass and 0.19 when only seeds are used. As the present study was carried out the first in Iran, therefore there are no data to be used to compare this system with other domestic systems. However, in a similar research conducted in Brazil, the energy productivity was reported to be 0.02 and 0.14 $kg.MJ^{-1}$ in traditional and mechanized farming systems respectively [15]. In the research carried out in Brazil, only the energy related to seeds was calculated. Moreover, the yield of native varieties used in the other countries was very low in comparison with that of Iranian local populations (850 and 1500 Kg per hectare). This is indicative of the necessity for the improvement of existing populations in order to facilitate the mechanized cultivation.

TABLE III. THE INPUT OF CONSUMABLE ENERGY AND RATIO OF USED ENERGY IN CASTOR PRODUCTION

Input		Unit	Energy equivalent (MJ)	Ratio of total used energy (%)
Human labor	Labor & Driver	h	250.8	2.23
seed		kg	244.8	2.18
Fertilizer, Herbicide & Pesticide	N	kg	4710	41.88
	P		395	3.51
	K		417.6	3.71
	S		252	2.24
	Treflan		255	2.27
	Diazinon		184.7	1.64
Irrigation		m^3	1890	16.81
Diesel fuel	Agricultural operations & Transfer to farm	L	2393.2	21.28
Build & Depreciation of farm machinery	Tractor	Kg	157.26	1.40
	Moldboard plow		8.15	0.07
	Rotary disc		37.62	0.33
	sprayer		3.14	0.03
	Fertilizer spreader		9.17	0.08
	drill		35.53	0.32
Maintenance of farm machinery	Tractor	Kg	0.81	0.01
	Moldboard plow		0.13	0.001
	Rotary disc		0.33	0.003
	sprayer		0.02	0.0002
	Fertilizer spreader		0.08	0.0007
	drill		0.31	0.003

TABLE IV. THE CONSUMABLE MATERIALS AND THEIRS COST ($) IN CASTOR PRODUCTION

Input		value	Unit	cost / Unit	Cost(total)
fertilizer, Herbicide & pesticide	N	100	Kg	0.27	27.27
	P	25	Kg	0.16	4.16
	K	45	Kg	1.06	47.72
	S	40	Kg	1.21	48.48
	Diazinon	1	Kg	8.48	8.48
	Treflan	3	Kg	6.06	18.18
seed		12	Kg	1.51	18.18
Total					172.5

TABLE V. OPERATION, FUEL COST ($) AND OPERATION'S TOTAL COST ($) IN CASTOR PRODUCTION

Operation	Diesel fuel(lit) or Electricity(Kwh)	Human labor (h)	Fuel cost (with subside)	Fuel cost (without subside)	Cost of the service
Planting, Cultivating, Harvesting	62	114	4.69	9.39	221.21
Peeling	20.706	42	0.58	0.58	60.60
Total			5.28	9.97	281.81

TABLE VI. COST OF PRODUCTION ($), COST($) PER KG OF SEED AND PROFITS($) FROM THE SALE OF GRAIN OF CASTOR IN IRAN

	Mode	Cost of Production	Cost per kg of seed	Profits from the sale of grain
1	All equipment and machinery belonging to farmer +The use of family labor +The use of Subsidized fuels	177.78	0.08	3004.03
2	All equipment and machinery belonging to farmer +The use of family labor +The use of fuel Without subsidy	182.47	0.08	2999.34
3	Using the services provided by the Agricultural Service Centers	454.31	0.21	2727.5

Cost of production include: Consumables materials (Table IV) and agricultural operation (Table V) from land preparation to harvested grain peeling.

As shown in Table VI for grain yield of 2100 kg per hectare, price per kilogram of grain in the first, second and third mode was 0.08, 0.08 and 0.21$ respectively.

Given 1.51 $ for each kilogram of unknown cultivar seed, which is currently sold in Iran, profit from the sale of grain was 3004.03, 2999.34 and 2727.5 $ in first, second and third mode, respectively.

Result show cost production per kilo of output energy in first, second and third mode is 0.0001, 0.0001 and

0.0002 $ respectively. According to these result castor is an affordable source for biodiesel production if upgrading happen for biodiesel production systems by more and more research.

IV. CONCLUSION

Considering the unique benefits of castor and the high energy use efficiency involved in its production, the development of the cultivation of this plant as a raw material for biodiesel production can be an effective step in using renewable fuels. On the other hand, the registration of local varieties, investigations to produce dwarf varieties and facilitating the design of the required machinery, and gradually replacing chemical fertilizers with the organic ones are among the important strategies for the development and expansion the cultivation of castor in conformity with ecological principles in Iran.

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