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Energy Balance for Camelina under Turkish Conditions

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Abstract: Widespread of camelina culture in Turkey will provide an alternative oil crop to country. With camelina culture, cooking oil deficit of the country may be reduced, pulp production may be increased and the plant can also be used as biodiesel source. Thus, camelina will definitely be a significant crop for the country economy. Energy balances are significant indicators in assessment and comparison of production methods. In this study, energy balance of camelina, a new crop in Turkey, was investigated. Experimental results and calculations for a yield of 0.756 t ha^{-1} revealed the total energy input as 15 347.20 MJ ha^{-1}, the total energy output as 77 390.73 MJ ha^{-1}, energy efficiency as 5.04 and the Net Energy Ratio (NER) as 4.04.

Keywords: Camelina sativa, biomass energy, energy balance

Türkiye Şartlarında Ketencik Bitkisinin Enerji Bilançosu

Öz: Türkiye'de ketencik bitkisinin geniş tarım alanlarında üretiminin yapılabilmesi ile alternatif bir yağ bitkisi kazanılacaktır. Bu bitkinin üretimiyle yemeklik yağ açığı azalabilir, küspe üretimi artabilir ve biyodizel kaynağı olarak kullanılabilir. Bu nedenle ketencik bitkisi ülke ekonomisi için gelecekte önemli bir bitki olabilir. Enerji bilançoları üretim yöntemlerinin değerlendirilmesinde ve karşılaştırılmasında önemli bir göstergedir. Bu araştırmada Türkiye'de tarımsal üretimi yeni olan ketencik bitkisinin enerji bilançosu araştırılmıştır. Yapılan denemelerde ve hesaplamalarda 0.756 t ha^{-1} verime bağlı olarak, toplam enerji girdisi 15 347.20 MJ ha^{-1}, toplam enerji çıktısı 77 390.73 MJ ha^{-1}, enerji kullanım etkinliği 5.04 ve net enerji oranı (NER) 4.04 olarak belirlenmiştir.

Anahtar Kelimeler: Cameline sativa, biyokütle enerjisi, enerji bilançosu

1. Introduction

Increasing world population also increases the demand for fossil fuels. Petroleum fuels (especially gasoline, diesel, natural gas and etc.) had various negative impacts on atmospheric canbondioxide levels and create several environmental problems. Therefore, alternative fuels, energy balances in their production processes and their environmental impacts through end-use in vehicles and engines have recently been the most widely searched issues. Right at this point, existence of different oil crops for biodiesel production especially for the vehicles with diesel technology should be assessed with an energetic perspective.

Soybean, rapeseed, sunflower and palm oil have significant places in world vegetable oil production (Carlsson 2009). In Turkey, sunflower, canola, soybean, safflower, sesame, peanut and poppy are the common oil crops. However, oil crops should further be diversified for a sustainable production. Among similar sources, camelina (*Camelina sativa* (L.) Crantz) is an alternative crop to be used as oil crop. There has been a recent positive revival in culture of camelina for oil seed production since it is sown in spring and thus has a positive sustainability aspect. However, oil seeds of camelina still have not sufficiently been utilized (Gehringer 2009).

Row spacings of camelina is 12.5 cm, sowing rate is 6-7 kg ha^{-1}, number of plant per unit area is 200 plant m^{-2} and sowing depth is 1-1.5 cm (Dobre and Jurcone 2011). In case of cultivation as the second crop, sowing norm is 6 kg ha^{-1}. The yield levels with sufficient irrigations (140 m^3 ha^{-1}) is around 1 203 kg ha^{-1} and the yield levels decrease down to 494.2 kg ha^{-1} without irrigations. Such values indicate considerably high yields under irrigated agricultural conditions (Dobre et al. 2014).

Significance of camelina is basically related to oil content of camelina seeds and such contents vary between 38 – 43 % (Gugel et al. 2006). About 15 % of camelina seed is constituted by unsaturated linoleic acid oil (18:2n-6) and about 38 % by α-linoleic acid (18:3n-3). High Omega-3 and Omega-6 fatty acid contents of camelina seeds make the plant as significant one also for human nutrition. The seeds are also used to meet the raw material needs of varnishes and cosmetic industry (Zubr 1997; Matthäus 2004) pharmaceutical industry (Berti et al. 2011).

Cetane number of biodiesel produced from camelina oil, iodine, oxidation stability and linoleic acid ester content negatively affect the quality of the biodiesel. Therefore, it has serious disadvantages with regard to biodiesel production and implementations (Davis et al. 2013; Örnek et al. 2013). Jet fuels produced from camelina oil were also comprehensively tested by the USA in commercial and military flights. Compared to petroleum-based jet fuels, camelina seed-based "hydrotreated" jet fuel met the entire jet engine performance expectations and significantly reduced the greenhouse gas emissions (Shonnard et al. 2010).

Energy balances are significant indicators in assessment and comparison of production methods used especially in energy farming. In Turkey, there are studies about energy balances of various plants such as sugar beet (Hacıseferoğulları et al. 2003; Erdal et al 2007), apricot (Gezer et al. 2003), pumpkin seed (Hacıseferoğulları and Acaroğlu, 2012), grape (Özkan et al. 2007), cherry (Kızılaslan 2009), seedless grape (Koçtürk and Engindeniz, 2009), dwarf apple (Yılmaz et al. 2010), rose oil (Gökdoğan and Demir 2013). However, the studies carried out with camelina are highly limited (Katar et al. 2012a; Katar et al. 2012b; Katar et al. 2012c). Those studies basically investigated oil content, yield and sowing parameters of the plant.

Agricultural mechanization constitutes the most expensive input in camelina culture. Thus, mechanization activities should be assessed through energy balances both to provide yield increase and cost reduction. Therefore, the present study was conducted to determine the energy balance of camelina. The relationships between input and output parameters of camelina were numerically compared through energy units.

2. Material and Method

The present study was conducted in Ereğli Region of Konya. Massey Ferguson 288 G/GOLD 4X4 tractors was used in experiments conducted in randomized block design with three replications over 4.20x100 plots. Experimental fields have loamy (L) texture with 68 % sand, 20 % clay and 12 % silt. The soils were slightly alkaline (pH=8.44), unsaline with insufficient phosphorus and very high lime levels.

Experimental fields were plowed with a moldboard plow on 10 March 2013. DAP fertilizer was applied at a rate of 200 kg ha^{-1} with a centrifuge-type fertilizer machine. The fields were then swept and a rotary tiller was used to prepare the seed beds.

The camelina seeds with a thousand kernel weight of 0.95 g were sown on 10^{th} of April. Sowing was performed with a vacuum-type pneumatic precision vegetable sowing machine able to sow small seeds. Sowing rate was set as 4.5 kg ha^{-1} and row spacing was arranged as 15 cm.

For field emergences, two sprinkler irrigations were performed for 4 hours during the initial month of sowing.

Fertilization was performed at the end of May with 33 % Ammonium nitrate at a rate of 100 kg ha^{-1}. Afolan was sprayed (175 g da^{-1}) for weed

control. A 45 kW submerged pump was used in irrigations, 4 irrigations were performed and a total of 850 m^3 ha^{-1} water was applied.

Human labor was used in harvests. Plants were manually harvested on 20th of July. Harvested plants were spread over a canvas and winnowed.

Fuel consumption of the tractor during the experiments was measured with a Rudolf Schmitt-brand fuel gauge (±0.5 %). Effective work performance of the machines was calculated by taking forward speeds and working widths of the machines into consideration.

The criteria specified in Table 1 were considered to determine the energy balance. Energy equivalents and camelina output energy equivalents are also provided in Table 2. Energy equivalents of camelina seed, shoot and pulp were determined at laboratories of Konya Cement Factory. IKA C7000-brand calorimeter device was used in those measurements.

Table 1. Definition of energetic parameters (Kaltschmitt et al. 2016)
Çizelge 1*. Enerji parametrelerinin tanımı*

Parameter	Definition	Unit
Direct energy inputs (E_d)	Input of diesel	MJ ha^{-1}
Indirect energy input (E_i)	Machines + Seed + fertilizers + herbicides, etc.	MJ ha^{-1}
Total energy input (E_T)	$E_T = E_d + E_i$	MJ ha^{-1}
Energy output (EO)	Energy in the harvested biomass	MJ ha^{-1}
Energy efficiency	EO/E_T	-
Net energy Ratio (NER)	$NER=EO- E_T/E_T$	-

Table 2. Energy equivalents of inputs and outputs in of camelina production
Çizelge 2. *Ketencik üretiminde girdi ve çıktıların enerji eşdeğerleri*

Input	Energy equivalent	Reference
Human labor	1.87 MJ kg^{-1}	Fluck (1992)
Water	2.95 MJ m^{-1}	Calısır (2007)
Seed	2.5 MJ kg^{-1}	Kaltschmitt and Reinhardt (1997)
Transportation (25 km)	9.22 MJ $(t\ km)^{-1}$	Kaltschmitt and Reinhardt (1997)
Herbicide (with Linuron active ingredient)	290 MJ kg^{-1}	Canavate and Hernandez (1999)
N	78.1 MJ kg^{-1}	Canavate and Hernandez (1999)
P_2O_5	17.40 MJ kg^{-1}	Canavate and Hernandez (1999)
Material production coefficient for tractor	49.453	Acaroğlu (1998)
Material production coefficient for steel	35.216	Acaroğlu (1998)
Fuel and oil	40.035	Kaltschmitt and Reinhardt (1997)
Extraction	1.245 MJ kg^{-1}	Riva and Sissot (1999)
Pelleting energy	0.5 MJ kg^{-1}	Acaroğlu (1998)
Output		
Camelina oil energy equivalent	38.20 MJ kg^{-1}	
Camelina pulp energy equivalent	18.08 MJ kg^{-1}	
Camelina shoot energy equivalent	17.80 MJ kg^{-1}	

Energy balances of entire inputs used in every process of camelina production such as tillage, fertilization, sowing, herbicide application, irrigation, harvest and transport were determined. Input and output values used in calculations were either measured under field conditions or taken from the previous literatures (Table 3).

Machine manufacturing energies of all machines used in camelina seed production were calculated by using the following equation (Yavuzcan 1994).

Table 3. Machinery used in camelina culture and their manufacturing energies
Çizelge 3*. Ketencik tarımında kullanılan makineler ve yapım enerjileri*

Agricultural Practices	Work performance (h ha^{-1})	Characteristics	Machine manufacturing energy (MJ kg^{-1})
Tractor	-	61 kW, 0.155 kg kWh^{-1}, 3340 kg, 6000 h life^{-1}	71.36
Plough	1.42	350 kg, 2300 h life^{-1}, 20 l ha^{-1}, work width 1.4 m	49.35
Centrifuge fertilizer spreader	0.14	100 kg, 1000 h life^{-1}, 2.5 l ha^{-1}, work width 10 m	104.93
Cultivator	0.91	400 kg, 2300 h life^{-1}, 8 l ha^{-1}, work width 2.75 m	48.96
Rototiller	1,25	700 kg, 2300 h life^{-1}, 21 l ha^{-1}, work width 2.35 m	48.96
Pneumatic precise sowing machine	2.5	525 kg, 1200 h life^{-1}, 6 l ha^{-1}, work width 2.8 m	63.34
Sprayer	0.29	140 kg, 750 h life^{-1}, 1.5 l ha^{-1}, work width 10 m	102.26

Mp= (Me+F) .0.82+Se
Mp : Machine manufacturing energy (MJ)
Me : Material production energy (MJ)
F : Factory energy (MJ)
Se : Spare part energy (MJ)

Unit-area energy inputs were then calculated by using the following equation;

$$M_{pe} = \frac{G.M_p}{T.W}$$

Mpe : Machine energy (MJ ha^{-1})
G : Mass of machine (kg)
T :Economic life of machine (h)
W : Work performance of machine (ha h^{-1})

3. Results and Discussion

The harvest resulted in a seed yield of 756 kg ha^{-1}. Oil ratio of the seeds was determined to be 35 %. The resultant pulp yield after extraction of the oil was 422.5 kg ha^{-1}. Shoot yield was calculated as 3282.5 kg ha^{-1}.

Mechanization energy inputs of camelina production are provided in Table 4. Among the mechanization implementations, human labor used during the harvest of camelina had the highest input with 30.57 %. It was followed by rotary tiller with 22.20 %, plowing with moldboard plow with 21.14%. Of the other mechanization implementations, precise sowing machine had an input value of 10.04 %, cultivator had a value of 8.90 %, centrifuge fertilizer distributor had a value of 5.25 % and sprayer had a value of 1.88 %.

Among the direct energy inputs, fuel-oil energy had the first place with a ratio of 59.81 %. It was followed by human labor energy with a ratio of 30.87 %. Of the other direct energy inputs, tractor and machinery manufacturing energy had a ratio of 9.32 %. These results revealed that harvest mechanization of camelina should be improved.

Direct and indirect energy inputs for camelina seed production are provided in Table 5. Considering the general energy inputs, fertilization had the first place with a ratio of 45.54% and it was followed by irrigation with 16.34% and fuel-oil energy with 16.04%. Relatively high energy inputs for fertilization and irrigation were mainly because of soil characteristics of the experimental fields. Experimental fields have high lime contents and very low organic matter contents. Fuel-oil energy input may be reduced through combined seed bed preparation combinations.

Total input and total output ratios in camelina culture were calculated based on measured and determined values and provided in Table 6. The Table presents total energy input, total output, specific energy, net energy and net energy ratio (NER).

Table 4. Energy inputs in mechanization of camelina production
Çizelge 4. *Ketenciğin üretim mekanizasyonunda enerji girdileri*

Agricultural practices	Work performance (h ha^{-1})	Tractor Manufacturing Energy (MJ ha^{-1})	Tool-Machine Manufacturing Energy (MJ ha^{-1})	Fuel + oil Energy (MJ ha^{-1})	Labor Energy (M Jha^{-1})	Total (MJ ha^{-1})
Tractor (MJ h^{-1})	-	39.72				
Plough	1.42	56.40	10.74	800.70	2.65	870.49
Centrifuge fertilizer spreader	0.14	11.12	4.24	200.18	0.52	216.06
Cultivator	0.91	36.14	8.51	320.28	1.70	366.63
Rototiller	1.25	49.65	21.29	840.75	2.34	914.03
Sowing machine	2.50	99.30	69.28	240.21	4.68	413.47
Herbicide application	0.29	11.52	5.45	60.05	0.54	77.56
Harvest (2 workers)	192.31	-	-	-	719.24	719.24
Smash and winnow	144.23	-	-	-	539.42	539.42
Total		**264.13**	**119.51**	**2 462.17**	**1 271.09**	**4 116.90**

Table 5. Distribution of overall energy inputs
Çizelge 5*. Genel enerji girdilerinin dağılımı*

Direct Energy Inputs	**MJ ha^{-1}**	**%**
Fuel-oil Energy	2 462.17	16.04
Tractor Energy	264.13	1.72
Labor energy	1 271.09	8.29
Machinery-tool Energy	119.51	0.78
Indirect Energy Inputs		
Fertilizer Energy	6 989.7	45.54
Herbicide Energy	228.38	1.49
Seed Energy	11.25	0.07
Irrigation Energy	2 507.50	16.34
Transportation	174.25	1.14
Extraction	941.22	6.13
Pelleting	378	2.46
Total Input	**15 347.20**	**100**

Table 6. Energy input and output values of camelina culture
Çizelge 6*. Ketencik tarımında enerji girdi ve çıktı değerleri*

Outputs	**Energy equivalent (MJ kg^{-1})**	**Energy Efficiency (MJ ha^{-1})**
Camelina seed (oil)	38.20	10 107.72
Camelina pulp	18.08	8 884.51
Camelina shoot	17.80	58 428.50
Total output		**77 390.73**
Net energy		**62 043.53**
Energy efficiency		**5.04**
Net Energy Ratio		**4.04**

4. Conclusion

The previous researches on energy plants revealed a net energy ratio of safflower as 11.03 (Acaroğlu and Unaldı 2009). The value was found to be 4.04 for camelina in the present study. The net energy ratio of camelina was relatively lower than safflower. In Azerbaijan, Output/Input ratio of canola was found to be 1.41. However, intensive labor and insufficient mechanization levels were also reported in the same study (Hassanzadeh-Gorttapeh et al. 2006). In Turkey, energy efficiency of canola for small and large agricultural enterprises was reported to be between 4.43 and 5.23 (Unakıtan et al. 2010). Fore et al. (2011) carried out a study and reported the net energy efficiency as 1.78 for canola biodiesel and as 2.05

for soybean biodiesel. Since canola has higher oil yield, it was pointed out as a significant source. Compared to other oil crops, field yields of camelina should be improved and researches should be carried out to reduce the input ratios in camelina culture. In this way, country economy may gain an economic oil crop.

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