Assessment of energy return on energy investment (EROEI) of oil bearing crops for renewable fuel production

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Abstract

As reported in literature the production of biodiesel should lead to a lower energy consumption than those obtainable with its use. So, to justify its consumption, a sustainable and "low input" production should be carried out. In order to assess the sustainability of *Linum usitatissimum, Camelina sativa* and *Brassica carinata* cultivation for biodiesel production in terms of energy used compared to that obtained, the index EROEI (Energy Return On Energy Invested) has been used. At this aim, an experimental field was realised in the south-eastern Sicilian land. During the autumn-winter crop cycle, no irrigation was carried out and some suitable agricultural practices have been carried out taking into account the peculiarity of each type of used seeds. The total energy consumed for the cultivation of oil bearing crops from sowing to the production of biodiesel represents the *Input* of the process. In particular, this concerned the energy embodied in machinery and tools utilized, in seed, chemical fertilizer and herbicide but also the energy embodied in diesel fuels and lubricant oils. In addition, the energy consumption relating to machines and reagents required for the processes of extraction and transesterification of the vegetable oil into biodiesel have been calculated for each crops. The energy obtainable from biodiesel production, taking into account the energy used for seed pressing and for vegetable oil transesterification into biodiesel, represents the *Output* of the process. The ratio *Output/Input* gets the EROEI index which in the case of *Camelina sativa* and *Linum usatissimum* is greater than one. These results show that the cultivation of these crops for biofuels production is convenient in terms of energy return on energy investment. The EROEI index for Brassica carinata is lower than one. This could means that some factors, concerning mechanisation and climatic conditions, were not suitable to ensure higher crop yields.

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Keywords: Biodiesel, EROEI, net energy balance, oil bearing crops, renewable energy.

Contributions: Restuccia A., data collected, data analyzing, manuscript writing and references search; Failla S., data analyzing, manuscript writing and references search; Longo D., Caruso L. data collected and references search; Mallia I., data collected, data analyzing and reference search; Schillaci G., reviewing.

Conflict of interests: the authors declare no potential conflict of interests.

Funding: the work was supported by the project AGROSO (Evaluation of high erucic acid oilseed species in the Mediterranean environment for use in the energy sector as an alternative to mineral oil with a high environmental impact) funded by MiPAAF (Ministry of Agriculture, Food and Forestry).

Journal of Agricultural Engineering 2013; XLIV(s2):e107
doi:10.4081/jae.2013.s2.e107

Introduction

In Europe, agriculture plays an important role in providing renewable energy resources. The quote of renewable energy deriving from this sector grew, in recent years, from 3.6% in 2005 to 10.5% in 2010. According to the GSE, in 2012, renewable resources production from agriculture brought in nearly 12,250 GWh (GSE, 2012; Ortenzi, 2013).

To achieve the main objectives set under the NES (National Energy Strategy), which was launched on 8 March 2013, it will need to take into consideration some strategic parameters including that relating to the energetic valorisation of biomass for the production of biofuels. It is also to highlight that the bio-energy production must create jobs as well as important opportunities for safeguarding the land and the national landscapes, especially in marginal lands (Monni, 2013).

In this context, to support the development of agro-energy in , it could be of great importance to focus on crops adapted to marginal land and non-irrigated or historically used for other crops and now being abandoned.

The cultivars of linseed (*Linum usitatissimum L.*) have been widely used in in the past years, recording a yield per hectare almost double the national average (Crescini, 1969: Rivoira, 2001).

The cultivars of *Brassica carinata* has attracted considerable interest also in , thanks to greater vigor, productive potential and increased resistance to biotic and abiotic stress shown by this species in some environments in respect of other varieties (eg. Brassica juncea and Brassica napus) (Mazzoncini *et al.*, 1993; Progetto Fi.Sic.A., 2008; Lazzeri *et al.*, 2009).

In addition, *Camelina sativa* together with other oilseed crops, have garnered interest as potential sources of biodiesel. *C. sativa* has attracted interest as an oil crop because of its ability to grow in various climatic conditions, low nutrient requirements and resistance to disease and pests (Zubr, 1996; Gugel and Falk, 2006; Francis and Warwick, 2009).

In summary, the choice of these high value species erucic, cultivated for energy purposes, derived from their ability to adapt to soil and climatic unfavourable conditions, enhancing thus the marginal areas or abandoned areas of agricultural land.

To be considered sustainable, the production of biodiesel (cultivation, extraction and trans- esterification) should involve lower energy consumption than those obtainable with its use. From energy audits conducted on rapeseed and sunflower it shows that to the phases of agricultural production and transesterification are attributed, in almost equal parts, about 76% of the total energy used and approximately 15 MJ/kg of biodiesel produced. Considering a calorific value of biodiesel equal to 37.3 MJ/kg, approximately 2.5 units of energy (biodiesel) per unit of energy consumed were obtained (Riva *et al.* 2008).

To assess, from point of view of energetic use, the economic advantages deriving from the cultivation of these crops in order to produce biodiesel, the index EROEI (Energy Return On Energy Invested) has been used. This energetic balance allows to correlate the amount of energy obtained from the crop (Output) with the amount of energy used for its cultivation (Input) as reported in literature (Cosentino *et al.*, 2008; Verani *et al.*, 2008; Lazzeri *et al.*, 2009; D'Avino *et al.*, 2010; Murphy *et al.*, 2010; Unakitan *et al.*, 2010; Pracha and Volk, 2011).

To obtain Input and Output data, energetic equivalents were be used, by choosing those reported in literature and most used (Baldini *et al.*, 1982; Volpi, 1992; Unakitan *et al.* 2010; Fore *et al.*, 2011).

Most recent energetic equivalents are reported in the literature and are worthy of note, but the values are often aggregated or missing and therefore it was not appropriate to consider them in this work (Singh *et al.* 2006; Ozkan *et al.* 2007; Da Silva *et al.* 2010; Zelina *et al.* 2011).

At last, this work is preliminary to a subsequent assessment of emissions of greenhouse gases (GHG), calculated taking into account the data input and output of the cultivation/production. This is to meet the sustainability criteria laid down for the supply chain of biofuels established with the RED (Directive 2009/28/EC).

Materials and methods

The experimental field

The experimental field was carried out in the province of Siracusa in south-eastern Sicily (36 ° 49'02 .61 "N 15 ° 05'33 .81" E); it covers an area of about with a maximum width of about and length of about . For this experiment, three non-irrigated plots were realised, one for each species concerned; each plot covers an area of and has a size ofof 80 m × 62 m. To avoid contamination between different species sown and to facilitate the mechanization of cultural practices, a buffer zones of between the plots and the edge of the area, and between the parcels have been left. The field is flat, rectangular in shape, oriented NW-SE and has an altitude of above sea level. The soil is compact, with lightweight skeleton presence and weaving of medium consistency.

The cultural practices and the machines

Due to the small size of oilseed crops, the tillage were carried out by performing a through preparation of the seed bed. At the beginning of December, a preliminary shredding of existing weed was carried out. The tillage was performed with a shredder having knives on a horizontal rotor, driven by the power take-off, of a width of 2.70 m and mass of 1,130 kg.

Subsequently, to break the compact layer of the surface soil and aerate it a harrowing was carried out. The farm machine used is a cultivator having 9 chisel plow shovels arranged in two rows, of a width of 2.25 m and mass of 500 kg. For the refinement of clods created in the previous tillage a hoeing was conducted. This tillage was carried out with a rotary tiller of a width of 2.05 m and mass of 450 kg.

Sowing and fertilization took place simultaneously in the third decade of December, by distributing 320 kg/ha of complex mineral fertilizer (NP 25-15) and 39 kg/ha of linseed, 4.2 kg/ha of seed *C. sativa* and 5.3 kg/ha of seed *B. carinata*.

For shredding, harrowing, hoeing, the farm machines were connected to a 4 WD tractor of 74 kW and mass of 3,500 kg.

The seeder used for linseed is universal type with mechanical distribution, 19 distributors and mass of 740 kg, double hopper for seed and fertilizer. The width is 2.50 m with adjustable spacing between the distributors (the minimum is 13 cm). In order to obtain a distance between the rows equal to 26 cm the distributors were used alternatively, by closing 9 of them. Because of the small size of the seed, the seed depth was maintained between 0.5 and 1 cm. The seeder was connected to a 4WD tractor of 74.5 kW and mass of 3,500 kg.

The seeder used for seeds of *C. sativa* and *B. carinata* is precision type with pneumatic distribution. It has three binate rows of distributors with a distance of 7 cm between rows and 40 cm between the binate rows, so as to obtain a working width of the machine equal to 1.60 m. In particular, the distance between rows was equal to 2.6 cm and the depth of sowing 1.5 cm for *B. carinata*, while the distance between rows was equal to 1.4 cm and the depth of sowing 0.5 cm for *C. sativa* because of the very small size of the seed. The distance between the binate rows was equal to 40 cm in both cases. The seeder was connected to a 2WD tractor of 44 kW.

After sowing, the rolling to make homogeneous the surface of the soil and a pre-emergence herbicide treatment were carried out. Doses of 1 L/ha of product with active ingredient "Linurom" in concentrations of 45 g/L, for linseed, and doses of 1 L/ha of product with active ingredient "Metazachlor" pure in concentrations of 43.5 g/L for the remaining crops were used. The volumes distributed were respectively 350 L/ha for linseed and 175 L/ha for other crops; these volumes correspond to the minimum recommended doses.

The rolling was performed with smooth roller having a width of 2.4 m and mass of 1000 kg, connected to a 4WD of 78 kW and mass of 2,540 kg.

The pre-emergence weed control was carried out by a bar sprayer 10 m wide and flat spray tips. The pressure during the treatment was 20 bar. The sprayer was connected to a 4WD tractor of 52 kW and mass of 3,200 kg.

During the growing season of the crop, periodic inspections of the experimental field were carried out which did not reveal the need to conduct additional cultural practices.

The harvesting of the experimental field was carried out in the first ten days of June, upon the completion of the seeds maturation, which was tested by sampling in the experimental field.

A combine harvester was used for the harvesting, commonly used for herbaceous crops, of 167 kW, mass of 10,400 kg and cutter bar of 5 m, by properly adjusting the speed of the awner and the opening of the threshing drum. In detail, given the small size of the seeds and not excessive resistance to detachment from the capsule by the same, the speed of rotation of the awner was set relatively low, amounting to about 850 rpm for *L. usitatissimum* and 650 rpm for *C. sativa* and *B. carinata.* The opening of the threshing drum was set of 6 mm anteriorly and 2 mm posteriorly for *L. usitatissimum* and 12 mm anteriorly and 3 mm posteriorly for *C. sativa* and *B. carinata*.

Subsequently, through appropriate laboratory tests were evaluated: the moisture content of the seeds, the thousand seeds weight mass of 1000 seeds and the number of seeds per capsule.

The methodology

In order to assess the sustainability of *Brassica carinata*, *Camelina sativa, Linum usitatissimum* cultivation for biodiesel production in terms of energy used (Input) compared to that obtained (Output), the index EROEI (Energy Return On Energy Invested) has been used.

The Output represents the energy which is possible to obtain by the products used for the cultivation, the Input refers to the factors of production used for the cultivation, whether direct or indirect (machinery and equipments, diesel fuel and lubricant oil, products for plant protection, fertilizers, etc.).

This methodology involves the use of the so-called energetic equivalents (or indexes), which represent, in the case of Input, the cost of energy incurred for the use of machinery during the various cultural practices and for the consumption of materials necessary for cultivation (seeds, fertilizers, herbicides, etc.), while, in the case of Output, the energy which can be obtained from the crop (vegetable oil, biodiesel, etc..).

For each farm machine used during the experimentation it was possible to find in the literature the energetic equivalent amount (expressed in MJ/h), which indicates the energy used per each hour of machine use; while the consumption of diesel fuel and lubricant oil are calculated separately (Baldini *et al.*, 1982; Unakitan *et al.* 2010). Energetic indexes were found in the literature also for seeds, fertilizers, herbicides, diesel fuel and lubricant oil, oil extraction and transesterification; these are expressed in MJ per unit of product (Baldini *et al.*, 1982; Volpi, 1992; Fore *et al.*, 2011).

To this end, in order to calculate the effective working capacities [ha/h] and then the time units of utilization [h/ha], the effective width of the work [m] and the forward speed [m/s] on the field for each cultural practice were recorded by adopting a standardized methodology.

The diesel fuel consumption was calculated through a direct measurement by using the "top-up" method on the field; furthermore they were verified through the sizing of power, necessary and sufficient, of the tractors used in the different cultural practices.

The consumption of lubricant oil was calculated by taking into account a specific consumption equal to 0,009 kg/kWh (Bodria *et al.*, 2006) and an engine load resulting from the ratio between the ideal power calculated through the sizing and the effective available power of the tractors used in the field.

In the case under consideration, the Output is represented by the energy content of biodiesel produced by the transesterification of vegetable oil mechanically extracted from seeds. The energetic equivalent for the biodiesel is considered equal to the calorific power that is 37.25 MJ/L (Avella *et al.*, 2009).

It is assumed that both for the extraction of oil from seed and for the transesterification of the same are required 5.31 MJ/L of biodiesel (Fore *et al.*, 2011), defined as energy consumed during the processes for machines (screw-press and transesterification machine), electricity, methanol and sodium hydroxide (reagents and catalysts). At the end, these Input data related to the process shall be in addition to those relating to the cultivation in order to obtain the total Input.

Results

Mechanization and agronomic viewpoint

The experimental trials has shown different results for the three species cultivated both for mechanization aspect and for agronomic aspects.

The cultural practices were carried out choosing carefully the machines both for their adaptability to the soil structure and to obtain a good final soil tillage in order to facilitate the crops in the first stages of growth. Moreover, accurate adjustments were carried out on the farm machines both in the farm workshop and in the open field, with particular attention to the seeder and to the harvester in order to optimize their efficiency and to reduce losses.

The three crops were grown in the same experimental field respectively in three similar plots for their physical-chemical features. The pre-sowing and post-sowing cultural practices were carried out at the same time for the three crops, so they gave back the same work capacity [ha/h] and unitary time [h/ha]. At the opposite, the sowing has recorded different values more or less remarkable both for the different wide of the seeders and for the different speed with the same seeder (Table 1). In fact, the mechanical seeder have a width double than the precision seeder. In addition, in order to ensure accurate seeding, the forward speeds were kept lower than those normally used in open fields which are greater to 2m/s with these seeders. For this reason also the working capacity were lower (about 1 ha/h) and unitary times higher of the average values found in field for the sowing. So, the percentage on the total of the cultural practices is quite high and equal to about 20% for *C. sativa* and *B. carinata* while 10% for *L. usitatissimum*.

As a result, the shredding is the practice that recorded the higher incidence on the total in respect to the other practices. It was around 40% for all the crops. The others tillage (harrowing and hoeing) showed similar percentage among 12 and 18% and together account for about 30%. Rolling, weeding and harvesting affect less than 8%, especially the weeding thank to the highest work capacity (about 3.3 ha/h).

The total unitary time is rather high for all three crops considered in respect to other crops, quite similar for the *C. sativa* and *B. carinata*

Table 1. Working capacity in the experimental field.

Cultural practices	Ve m/s	Le m	Ce ha/h	Unitary time h/ha	Incidence *L. usitatissimum*	 *C. sativa*	 *B. carinata*
Shredding	0.35	2.50	0.32	3.17	42%	38%	38%
Harrowing	1.40	2.05	1.03	0.97	13%	12%	12%
Hoeing	1.10	1.90	0.75	1.33	18%	16%	16%
Sowing and Fertiliz.							
- *L. usitatissimum*	1.55	2.35	1.31	0.76	10%		
- *C. sativa*	1.56	1.15	0.65	1.55		19%	
- *B. carinata*	1.29	1.30	0.60	1.66			20%
Rolling	2.20	2.20	1.74	0.57	8%	7%	7%
Weeding	0.95	9.70	3.32	0.30	4%	4%	4%
Harvesting	1.40	5.00	2.52	0.40	5%	5%	5%
		TOTAL	*L. usitatissimum*	7.51	100%		
			C. sativa	8.29		100%	
			B. carinata	8.40			100%

(8.3-8.4 h/ha) and a little lower for the *L. usitatissimum* (7.5 h/ha) due to a greater work capacity of the sowing.

For each crop, in addition to the yield, the thousand seed weight, the relative humidity and the number of seed for capsule have been evaluated (Table 2).

As a result, the agronomic parameters obtained are comparable with those found in literature, except for the *B. carinata* yield. In this last case, the delayed sowing period for this crop has probably led to a reduction in yield which can still oscillate between 0.1 and 1.2 t/ha (Monti and Venturi, 2007).

The yield of *L. usitatissimum* was very similar (1.45 t/ha) to that reported in literature that is of about 1.52 t/ha (Rivoira, 2001). Even the weight of a thousand seeds is one of the values listed in the bibliography: the thousand seeds weight could be in a range between 3 and 15 g (Crescini, 1969) and for most of commonly variety cultivated between 5 and 10 g (Rivoira, 2001).

In the case of *C. sativa*, the yield was about 1.1 t/ha and the thousand seeds weight was about 1.15 g as reported in other studies where yield was between 1.1 and 3.3 t/ha and thousand seeds weight of about 1.2 g (Crescini, 1969; Zubr, 1996; Gugel *et al.*, 2006).

Regarding *B. carinata*, a recent study performed in Sicily reports a yield of about 1.5 t/ha, that is more than that harvested with the experimental trials and thousand seeds weight of about 3.3 g that is little less than value reported in Table 1 for this crop (Progetto Fi.Sic.A., 2008).

Energetic viewpoint

In order to evaluate the sustainability of the energetic crops the EROEI index was calculated. To do this, the energy gained with the biodiesel producible and that consumed for machines and products used were compared.

In Table 3 is reported the energy consumption for the use of the machine due to the energy embodied in each of them.

The cultural practice that recorded the maximum Energy required was the shredding with an incidence between 34.5 and 38.1% on the total. This result is strictly related to the high unitary time required by the tillage.

Likewise, the sowing was again the practice that recorded the maximum difference among the three crops due to the different seeders used. In fact, for *L. usitatissimum* cultivation a value of about the half than the others two crops was registered. Moreover, only one point percentage of difference between *C. sativa* and *B. carinata* was recorded.

On the other hand, the chemical weeding showed the lower energy consumption a little bit more than 1%, also because of the lowest values of energetic equivalents considered in this cultural practice for the tractor and the operating machine.

The total for each crop shows negligible differences between the species and amounts to a few tens of MJ/ha, due only to the different unitary times of the sowing.

The detailed consumptions of fuel and lubricant are reported in Table 4, where also the percentage of every single practice for each culture is showed.

As already seen for the use of the machines in Table 3, even in this case the differences among the fuel and lubricant consumptions are strictly related to the unitary time needed to carry out each cultural

Table 2. Agronomic parameters.

Crop	Yield	Thousand seeds weight	Relative humidity	Seeds per capsule
	t/ha	g/1000 seeds	%	n
L. usitatissimum	1,45	4,93	8,33%	9
C. sativa	1,10	1,15	6,26%	11
B. carinata	0,85	3,12	11,74%	15

Table 3. Energy consumption due to use of machines.

Cultural practices	Unitary time	Energetic index tractor	Energetic index operating machine	Energy required tractor	Energy required operating machine	Total	Incidence *L. usitatissimum*	Incidence *C. sativa*	Incidence *B. carinata*
	h/ha	MJ/h	MJ/h	MJ/ha	MJ/ha	MJ/ha	%	%	%
Shredding	3.17	27.13[1]	2.26[1]	86.13	7.17	93.30	38.1%	34.9%	34.5%
Harrowing	0.97	27.13[1]	6.07[1]	26.26	5.87	32.13	13.1%	12.0%	11.9%
Hoeing	1.33	27.13[1]	2.51[1]	36.06	3.34	39.39	16.1%	14.7%	14.6%
Sowing and fertilizing									
- *L. usitatissimum*	0.76	27.13[1]	1.76[1]	20.69	1.34	22.03	9.0%	-	-
- *C. sativa*	1.55	27.13[1]	1.76[1]	42.01	2.73	44.73	-	16.7%	-
- *B. carinata*	1.66	27.13[1]	1.76[1]	44.94	2.92	47.85	-	-	17.7%
Rolling	0.57	27.13[1]	6.07[1]	15.57	3.48	19.05	7.8%	7.1%	7.0%
Weeding	0.30	13.08[1]	0.61[1]	3.94	0.18	4.13	1.7%	1.5%	1.5%
Harvesting	0.40	87.63[2]	-	34.77	-	34.77	14.2%	13.0%	12.8%
				TOTAL	*L. usitatissimum*	244.81	100%	100%	100%
					C. sativa	267.52			
					B. carinata	270.64			

[1] Baldini *et al.*, 1982; [2] Unakitan *et al.*, 2010.

practice. In fact, in all cases, the tillage and harvesting recorded in total more than 80% of the consumption, while the rolling and the chemical weeding were always equal or less than 2%. Also the sowing confirmed a big difference when different seeder was used (about 10%) and again a small difference when the same seeder was used in two different species (about 1%).

This result primarily affects the total amount of diesel fuel consumed in three crops. In particular, the cultivation of *L. usitatissimum* involves a saving of about 7-8 kg/ha compared to the other two crops considered.

To assess the total energy consumption for all the products used, fertilizer, herbicide and seeds were considered together to diesel fuel and oil lubricant (Table 5).

Looking at the Table, it appears that the fertilizer represents the product which involves the higher Energy required with value around 7 thousand MJ/ha (about 60% on the total). Also the values of Energy required for the diesel fuel consumption are quite high and around to 3.400 to 3.800 MJ/ha. This two products represent together about 90% of the total of Energy required for the use of the products during the cultivations.

In the case of *L. usitatissimum* the use of seeds is energetically relevant because of the high quantity used for sowing (39 kg/ha). The seed represents about 8% of the total Energy required, while for the other two species it remains around to 1%.

An analysis of the energy consumption relating to machinery, diesel fuel, lubricant oil, fertilizer, herbicide and seed showed that the sowing together to the fertilizing becomes the cultural practice which requires more than 65% of total energy used for the cultivation (Figure 1). The alignment of values concerning the sowing and fertilizing in the three crops is due principally to the amount of energy required to the fertilizer used.

Despite the use of herbicide, the chemical weeding remains, after rolling, the practice that requires the smallest amount of energy. This

Table 4. Diesel fuel and lubricant oil consumption.

Cultural practices	Diesel fuel [kg/ha]	Incidence *L. usitatissimum*	Incidence *C. sativa*	Incidence *B. carinata*	Oil lubricant [kg/ha]	Incidence *L. usitatissimum*	Incidence *C. sativa*	Incidence *B. carinata*
Shredding	17.10	26.6%	23.8%	23.6%	0.55	25.0%	22.7%	22.5%
Harrowing	12.53	19.5%	17.5%	17.3%	0.45	20.6%	18.6%	18.4%
Hoeing	17.21	26.8%	24.0%	23.8%	0.62	28.2%	25.6%	25.3%
Sowing and fertilizing								
- *L. usitatissimum*	2.12	3.3%			0.08	3.5%		
- *C. sativa*	9.54		13.3%		0.31		12.6%	
- *B. carinata*	10.20			14.1%	0.33			13.4%
Rolling	1.10	1.7%	1.5%	1.5%	0.04	1.8%	1.6%	1.6%
Chemical weeding	1.27	2.0%	1.8%	1.7%	0.04	1.9%	1.7%	1.7%
Harvesting	12.99	20.2%	18.1%	17.9%	0.42	19.0%	17.2%	17.1%
TOTAL *L. usitatissimum*	64.32				2.19			
C. sativa	71.75	100%	100%	100%	2.43	100%	100%	100%
B. carinata	72.41				2.45			

Table 5. Energy consumption for all the products used during the cultivation

Product	Quantity kg/ha	Energetic index MJ/kg	Energy required MJ/ha	*L. usitatissimum* %	*C. sativa* %	*B. carinata* %
Diesel fuel						
- *L. usitatissimum*	64,3	52,34[1]	3,366	28.35%		
- *C. sativa*	71,8	52,34[1]	3,756		32.99%	
- *B. carinata*	72,4	52,34[1]	3,789			33.10%
Oil lubricant						
- *L. usitatissimum*	2,20	45,51[1]	100	0.84%		
- *C. sativa*	2,43	45,51[1]	111		0.97%	
- *B. carinata*	2,45	45,51[1]	111			0.97%
Fertilizer	320	22.09[1]	7,069	59.53%	62.09%	61.75%
Herbicide	1.0	343.32[1]	343	2.89%	3.02%	3.00%
Seeds						
- *L. usitatissimum*	39	25.54[2]	996	8.39%		
- *C. sativa*	4.2	25.54[2]	107		0.94%	
- *B. carinata*	5.3	25.54[2]	135			1.18%
	TOTAL	*L. usitatissimum*	11,875	100%	100%	100%
		C. sativa	11,386			
		B. carinata	11,448			

[1] Baldini *et al.*, 1982; [2] Volpi, 1992.

is due to the small dose required for after sowing treatment for oilseed crops.

Finally, in order to calculate the total energetic Input for the cultivation of one hectare of the three different oilseed crops, the amount of biodiesel producible from each crop is estimated. By considering the yields reported in Table 2 and an oil yield of 35% for *L. usitatissimum* (Rivoira, 2001), of 38% for *C. sativa* (Gugel and Falk, 2006) and of 36% for *B. carinata*, it is possible to obtain respectively 507, 418 and 306 kilograms of vegetable oil. Moreover, a recent research shows that yields between 88 and 96 kg of biodiesel from transesterification of 100 kg of vegetable oil under alkaline catalysis condition are obtainable (Kumar *et al.*, 2013). The authors also report that the yield differences observed are related to the amount of reagent, catalyst and process temperature employed. Taking into account a mean yield of 92% from the quantities reported above is possible to obtain the biodiesel amounts showed in Table 6.

The total energetic Input data of the process are closely related to the yields and therefore higher values are those of *L. usitatissimum*, follow to the *C. sativa* and *B. carinata*. Similarly also the total amount of energy consumed follows the same order. However, the values obtained are lower than those reported in literature for other crops (Cosentino *et al.*, 2008).

In *L. usitatissimum* and *C. sativa* cases, the EROEI index is bigger than one. It means that these two cultivation are energetically convenient. At the opposite the EROEI index of *B. carinata* is less than one. In this case we spent more energy than we gained from the seeds harvested. However, if we consider the average yield of 1.5 t/ha found by other authors, a biodiesel production of about 596 kg/ha could be obtainable. In this way the biodiesel production could be around to 621 L/ha which determines an EROEI index of 1.7.

Conclusions

The study aimed to verify the technical and economic feasibility of oil bearing crops such as *Linum usitatissimum, Camelina sativa* and *Brassica carinata*, grown for energy purposes for the production of fuel oils and biodiesel. Besides these crops could also get in rotation with durum wheat also in order to improve its productivity.

The experiment performed in Sicily suggests that is possible to use non-irrigated soils for these energetic crops, but the correct cultural practices and sowing period are crucial to obtain good yields. However these were comparable with those reported in literature.

It's important to note, however, that the values of Input are lower than those reported in literature for other crops.

Moreover, in order to decrease the energy input could be reduced the amount of fertilizer to be used. In fact, it represent more than 50% of the totally energy invested.

A correct soil management could be useful to reduce weeds existent and so to eliminate the shredding that is one of the most expensive cultural practices in term of energy consumption.

In order to reduce energetic costs and work time, due to two-three tillage and rolling, the direct sowing with simultaneous tillage and sowing could be checked.

Also a correct use and choosing of the seeder can affect the energy consumptions as in the case object of study. In this regard, the cultivation of *L. usitatissimum* involves a saving of about 7-8 kg/ha compared to the other two crops considered: on larger farms, these differences can have a considerable economic impact.

The EROI index, even with the limitations inherent in the experimental test in object, is bigger than one for *Linum usitatissimum* and *Camelina sativa*, while it is less than one for *B. carinata* because of the delayed of sowing of the crop.

Although the results obtained, using the index EROEI, are partial with respect to an overall assessment which provides also for the calculation of greenhouse gas (GHG) emissions, the study in question is a first step to promote the cultivation of oil bearing crops in agricultural areas marginal or abandoned.

Moreover, it was estimated that biodiesel may be more convenient than diesel when the oil prices reach 75 €/barrel and even greater economic competitiveness may result from the recognition of the environmental benefits coming from the full chain of biofuels (Monti and Venturi, 2007).

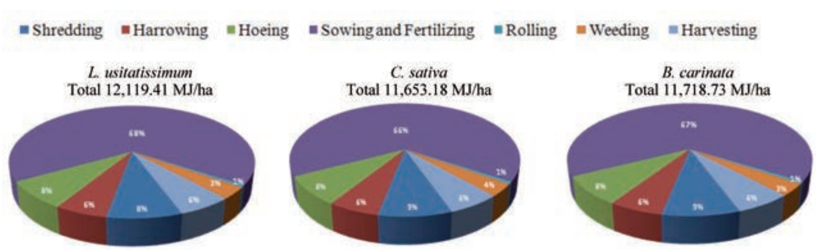

Figure 1. Energy use of machinery, diesel fuel, oil lubricant, seeds, herbicide and fertilizer for each cultural practice in the three crops.

Table 6. Input, output and EROEI index.

Crop	Biodiesel L/ha	Input energetic index MJ/L	Process input MJ/ha	Cultivation input MJ/ha	Total input MJ/ha	Output energetic index MJ/L	Total output MJ/ha	EROEI
L. usitatissimum	583,62	5.31[1]	3099,05	12,118.34	15217,39	37.25[2]	21740,03	1,43
C. sativa	480,70	5.31[1]	2552,52	11,651.06	14203,58	37.25[2]	17906,08	1,26
B. carinata	351,90	5.31[1]	1868,59	11,719.19	13587,78	37.25[2]	13108,28	0,96

[1]Fore *et al.*, 2011; [2]Avella *et al.*, 2009.

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