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On Farm Agronomic and First Environmental Evaluation of Oil Crops for Sustainable Bioenergy Chains

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Abstract

Energy crops, and in particular oil crops, could be an important occasion for developing new non food production rows for a new multi-functional agriculture in Italy. In this view, the use of local biomass is a fundamental starting point for the development of a virtuous energy chain that should pursue not only agricultural profitability, but also chain sustainability and that is less dependent on the global market, characterized by instability in terms of biomass availability and price. From this perspective, particular attention must be paid to crop choice on the basis of its rusticity and of its adaptability to local growing conditions and to low input cropping systems. In this context, alike woody and herbaceous biomasses, oil crops such as sunflower and rapeseed should be able to support local agricultural bioenergy chain in Italy.

In addition, in a local bioenergy chain, the role of the farmers should not be limited just to grain production; but also grain processing should be performed at farm or consortium level in oilseed extraction plants well proportioned to the cropped surface. In this way, by means of a simple power generator, farmer could thus produce its own thermal and electric energy from the oil, maximizing his profit. This objective could also be achieved through the exploitation of the total biomass, including crop residues and defatted seed meals, that may be considered as fundamental additional economic and/or environmental benefits of the chain. This paper reports some results of three-years on-farm experiments on oil crop chain carried out in the framework of "Bioenergie" project, that was focused to enhance farmers awareness of these criteria and to the feasibility at open field scale of low-input cultivation of rapeseed, sunflower and *Brassica carinata* in seven Italian regions. In several on-farm experiences, these crops produced more than 800 kg ha⁻¹ of oil with good energy properties. Defatted seed meals could be interesting as organic fertilizers and, in the case of *B. carinata*, as a biofumigant amendment that could offer a total or partial alternative to some chemicals in agriculture. Furthermore, biomass soil incorporation could contribute to C sequestration, catching CO₂ from atmosphere and sinking a part in soil as stable humus. Finally, four different open field experiences carried out again in the second year of the project, have been analysed in order to evaluate their energy and greenhouse gasses balance after cultivation phase.

Key-words: *Brassica carinata*, carbon dioxide sequestration, defatted seed meals, greenhouse gasses, inputs.

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Introduction

The decision of the European Community (Directive 2009/28/EC published in OJ 5.6.2009 and the Commission Decision of 30.6.2009 on National Renewable Energy Action Plans) on renewable energy sources has opened important development perspectives in relation to the ambitious objectives on biofuel production within the EU by 2020. Nevertheless, clear sustainable criteria are fundamental to define new development models specific for the EU countries agricultural systems including Italian one that is characterised by both limited land availability for bioenergy crop production and higher grain production costs than those of other EC or non-EC countries. In the first two years of on-farm experiments, the “Bioenergie” project proposed a development model for the oil crop supply chain, as an alternative to the conventional industrial model currently applied in Italy.

The proposal essentially consists in the development of a local supply chain, where oil crops should be grown as break crops in cereal cropping systems in different agricultural districts at various scales (farmers’ associations, cooperatives, consortia, etc.). In this context, farmers, as well as grain producers, should perform also oil extraction process by means of an on-farm mechanical plant designed according to the cropped area. Farmers thus may become producers and end-users of the energy obtained from crude vegetable oil, maximising their profit and reducing energy chain environment impact. To balance the lower potential production of oil crops in Italy if compared to other countries, a basic point could be to gamble on a “whole-use” of plant biomass, as a tool to achieve improved economic and environmental sustainability (Bezzi et al., 2007). According to the concept of “biorefinery” approach (Kamm et al., 2006; Lazzeri and D’Avino, 2008), the chemical industry should set up new cost-effective technologies to produce not only energy, but also safer chemical compounds to develop sustainable innovative strategies aimed at creating an environmentally friendly alternative to chemicals. The economic exploitation of co-product potential can improve the chances for bioenergy crop systems (Venturi and Venturi, 2003).

Food crops must obviously remain the first source of income for the national agricultural

sector, but energy crops, cultivated in rotation with food crops, can contribute to increase biodiversity at farm scale and consequently to improve the qualitative and quantitative yields of the food crops in rotation. Starting from this approach, it is fundamental to increase the use of virtuous cultivation techniques in crop management (e.g. low inputs, crop rotations etc.) as much as possible in order to reduce Greenhouse gasses (GHG) emissions (Janssen et al., 2003) during cultivation phase and/or to increase the carbon sequestration potential after the incorporation of part of the biomass (crop residues, defatted seed meals). This proposal could provide a possible answer to the 2009/28/EC Directive which, for the first time, defines sustainability criteria specific for energy crops, and defines the rules for calculating the GHG impact of biofuels starting from emission during the cultivation phase.

Considering that on-farm, participatory researches can promote rapid adoption of agricultural innovations (Wuest et al., 1999; Andrews et al., 2002), allow a multidirectional flow of information among farmers and researchers (Tanaka et al., 2002).

The aim of on-farm work is to report some preliminary results achieved in 7 representative localities out of a total of 15 open field cultivation trials carried out during 2007-2008 in eight Italian Region (Fig. 1). In each experimental site, *Brassica carinata* (Mazzoncini et al., 1993), a model of “whole-use” energy crop (Lazzeri et al., 2007a), was compared to the most suitable oil crop for each specific agro-climatic condition: high oleic sunflower (*Helianthus annuus* var. High oleic (HOSO) and/or rapeseed (*Brassica napus* var. *oleifera*). A second aim of this work was to report some chemical-physical properties and the potential of defatted seed meals (DSM) in the non-food market on the basis of their chemical composition.

Finally, some results of energy and environmental balances related to four specific sites located in Veneto, Emilia Romagna, Tuscany and Apulia will be reported and discussed.

Materials and methods

2.1 Experimental sites

The on-farm trials of the project were carried out for three years at open field scale in private



Figure 1. On farm trial locations of the "Bioenergie" project in the year 2007-2008.

farms, on a surface of at least 1 ha for each crop, applying common farm mechanisation methods, even if the trials and the results were evaluated also by a three-replicate randomised samplings. The trials were located in seven Italian regions: Veneto – Po di Tramontana (Rovigo); Emilia Romagna – Lugo (Ravenna); Marche – Recanati (Ancona); Tuscany – Roccastrada (Grosseto); Apulia – Gravina in Puglia (Bari); Sicily – Ispica (Ragusa) and Sardinia – Ottana (Nuoro).

The on-farm trials for the evaluation of sustainability balance were located: in Veneto – Po di Tramontana (Rovigo), Emilia Romagna – Budrio (Bologna), Tuscany – San Piero a Grado (Pisa) and Apulia – Gravina in Puglia (Bari).

2.2 Experimental design

The cropping techniques were defined in relation to the specific characteristics of each area, according to a common low input prescription model characterized by different energy inputs (e.g. a different expenditure of technical means, soil tillage, fertilizers and chemical treatments) as described in Table 1. In each site, *Brassica carinata* (carinata) and *B. napus* were sown between end September-beginning of October (in the north) and second half of November (in the south). Sunflower was sown in spring, between March and April.

In three localities (Tuscany, the Marche and

Apulia) low input techniques were compared to high input techniques. The differences between high and low input techniques are described in Table 2.

The cultivation techniques of the on-farm trials for sustainability balances are reported at 2.4 paragraph.

The on-farm design was long strips side-by-side in the field. Typically, strips are field length and one or two tractors passes wide (Sooby, 2001).

The results of this study are referred to the data of the second year of the project (2007-2008) and evaluated on the basis of data collected by the whole fields and by three replications for each field strips. Replicated observations were statistically analysed using completely randomized design ANOVA performed with SigmaStat 3.11 (Systat software Inc.). LSD Fisher's protected test ($P \leq 0.05$) was applied for mean separation. The yield recorded by the harvesting of the whole fields were compared using standard errors.

2.3 Measurements

At ripening, (seed moisture lower than 90 g kg⁻¹) three randomized sample areas of 2 m² were collected within each experimental field to assess harvestable crop yield. The plants were manually cut and gathered and then threshed

Table 1. Low-input cropping techniques applied at each experimental site.

Region	Sites	Crop*	Cultivar	Tillage	Sowing technique		Fertilization (kg ha ⁻¹)			Weed management
					Inter-row (m)	Seed Density (kg ha ⁻¹)	N	P ₂ O ₅	K ₂ O	
Veneto	Po di Tramontana (RO)	C	ISCI7	Subsoiling + Disk harrowing + Rotary tillage	0.45	4.5	130	90	90	Chemical pre-emergence
		R	Excalibur		0.45	4.5	130	90	90	
Emilia Romagna	Lugo (RA)	C	CT 207 ISCI7	Ploughing + Rotary tillage	0.15	8	0***	0	0	
Tuscany	Roccastrada (GR)	C	CT207	Disk harrowing + shallow chiselling	0.15	11	0***	0	0	
		R	PR46W10		0.15	10	0***	0	0	
		H	PR64H41	Chiselling + disk and rotary harrowing	0.75	6.5 **	60	30	30	Chemical post emergence
Marches	Recanati (AN)	C	ISCI7	Disk harrowing + Rotary hoeing	0.15	8	92	70	0	Chemical Pre-emergence
		H	PR64H41	Disk harrowing + Zig zag harrowing	0.50	6 **	119	70	0	
Apulia	Gravina di Puglia(BA)	C	ISCI7	Ripper + 2 Harrowing	0.15	8	49	20	0	
		R	PR46W10		0.15	5	49	20	0	
Sicily	Ispica (RG)	C	CT 207 ISCI7	Ripper + Hoeing	0.18	10	48	65	0	Chemical pre-emergence
Sardinia	Ottana (NU)	C	BRK147	Ploughing + Rotary tillage	0.18	8	50	60	0	Mechanical
		R	Kabel		0.18	8	128	92	0	Chemical pre-emergence

* C stands for Brassica carinata; R for rapeseed; H for high oleic sunflower.

** For sunflower, sowing density is reported as plant m⁻² and not as kg of seeds ha⁻¹.

*** Fertilization test carried out to quantify nutrient supply from the environment.

Table 2. Differences between high and low input cultivation techniques described in Table 1.

Region	Location	Crop*	Difference between HI and LI	
Tuscany	Roccastrada (GR)	C	Soil tillage:	no differences
			Fertilisation:	27 kg ha ⁻¹ N, 69 kg ha ⁻¹ P ₂ O ₅ , 0 kg ha ⁻¹ K ₂ O (HI) instead of 0-0-0 (LI)
			Weed management:	chemical pre-sowing in HI instead of nothing (LI)
		R	Soil tillage:	no differences
			Fertilisation:	27 kg ha ⁻¹ N, 69 kg ha ⁻¹ P ₂ O ₅ , 0 kg ha ⁻¹ K ₂ O (HI) instead of 0-0-0 (LI)
			Weed management:	chemical pre-sowing in HI instead of nothing (LI)
		H	Soil tillage:	mouldboard 35 cm (HI) instead of chiselling 35 cm (LI)
			Fertilisation:	120 kg ha ⁻¹ N, 60 kg ha ⁻¹ P ₂ O ₅ , 60 kg ha ⁻¹ K ₂ O (HI) instead of 60-30-30 (LI)
			Weed management:	pre-sowing chemical control + mechanical weeding (HI) instead of post-emergence chemical weed control
Marches	Recanati (AN)	C	Soil preparation: chiseling (HI) instead of disk arrowing (LI)	
		H		
Apulia	Gravina di Puglia (BA)	C	Soil tillage: no differences Fertilisation: double in HI (97 kg ha ⁻¹ N, 40 kg ha ⁻¹ P ₂ O ₅) Weed management: chemical pre-sowing in HI	
		R		

* C stands for Brassica carinata; R for rapeseed; H for high oleic sunflower. HI high input cultivation techniques LI low input cultivation techniques.

by a fixed machine, using sieves suitable for small seeds, and evaluated for their moisture, seed and crop residue yields. The moisture was measured by oven-drying the seeds at 105 °C for 24 hours. After harvesting, impurities were removed from a sample of the seed and oil, protein and glucosinolates were determined. Crop residues were evaluated for their N amount. After sampling, the entire field was harvested by a combine equipped with a straight cut header.

The seed oil concentration was determined by the NMR (Nuclear Magnetic Resonance) technique, using a specific calibration for each species on an Oxford Newport 4000 instrument. N content was determined by the Kjeldahl method assessed using an automatic titre distiller Vapodest 6 Gerhard (Germany).

A part of the seed yield was defatted by a mechanical plant of Mailca (Modena, Italy) and the residual defatted meals were assessed for Kjeldahl N, P (Cottenie et al., 1982) and C contents. Carbon content was assessed as the difference from dry matter biomass and ashes and multiplied by 0.4, the coefficient for vegetable materials.

2.4 Sustainability balances

Sustainability balances was carried out merely in *carinata* cultivated in four localities among those reported in Figure 1. The cultivation techniques adopted was slightly different by those reported in Table 1 and 2, and characterised by high inputs in Veneto and by low inputs in Emilia Romagna, Tuscany and Apulia. In particular soil preparation was performed by mouldboards in Budrio, spading machine in Po di Tramontana, ripper in Gravina and no-tillage in San Piero a Grado. In these trials, N fertilization ranged between 54 in Gravina and 170 kg ha⁻¹ in Po di Tramontana, where also an emergency irrigation was needed. In Gravina no chemical weed management was applied, while in San Piero a Grado only one treatment by glyphosate was done before sowing.

The approach was essentially that of LCA (Consoli et al., 1993) but, following the indications of the recent Directive for energy crops (Dir 2009/28/EC), the analysis has been focused on assessing the Global Warming Potential (GWP), which is a measure of the global rise in temperature due to the increase of GHG in the atmosphere. The considered GHG were CO₂,

N₂O, CH₄. As suggested by IPCC (2001), their effects were converted into a final GWP measured in mass quantity of CO₂ eq. considered over a 100-year timescale, assuming the following equivalences: CO₂ = 1, CH₄ = 23 and N₂O = 296. Following the rules for calculating the GHG impact described in Dir 2009/28 EC, emissions from the manufacture of machinery and equipment has not been taken into account. Furthermore, the impact on Energy Resources Depletion (ERD) expressed in MJ of primary energy required by the production process was also evaluated.

The hectare, the mass unit of product (kg), and one MJ of biodiesel were considered as the functional units to which impacts were referred, following the EU Directive references. Field yield expressed as mass (kg) of biodiesel was evaluated considering the oil extracted from the grain produced in the different localities and the percentage of biodiesel obtained from *carinata*-oil of 97.6% (Cordovani, personal communication). The extracted oil was evaluated considering the specific oil content measured as described in the previous paragraph and assuming an oil content in residual oilcake of 11% (as reported in Table 6).

To calculate the obtained Energy (Eo) value, the Net Calorific Value (NCV) of biodiesel was assumed equal to 37 MJ/kg as indicated in the Directive 2009/28/EC. Grain NCV was calculated considering *B. carinata* oil (ASTM D 240-07) and DSM NCV (CEN/TS, 2005).

Coefficients for primary energy consumption and GHG emissions for every unit of input applied in the cultivation process were taken from Audsley (1997), as reported in Table 3. The required energy and CO₂eq emissions coefficients for N-P-K fertilizers were calculated multiplying the percentages of N, P₂O₅ and K₂O by the coefficients of each macronutrient and then adding the results. The GHG emissions of use of fertilizers were not taken into account in the evaluation of CO₂eq.

Results and discussion

The conventional oil crops confirmed their feasibility as energy sources. In some locations, even under open field conditions, more than 800 kg ha⁻¹ of oil were produced (Veneto for rape-

Table 3. Required energy (MJ) and GHG emissions (CO₂eq) per unit of input following Audsley (1997).

Category	Inputs	Unit	Coefficients	
			Energy (MJ/unit)	CO ₂ eq. (kg/unit)
<i>Energy sources</i>	Diesel	lt	38.46	2.96
<i>Fertilizers</i>	Ammonium nitrate	kg	12.75	0.38
	Ammonium sulphate	kg	10.30	0.31
	Urea	kg	31.62	1.33
	Organic NP (8-15-0)	kg	8.72	0.58
	NPK (8-24-24)	kg	12.92	0.99
	NPK (11-22-16) + 2MgO	kg	14.37	1.03
	Bioactyl (8-10-22)	kg	8.34	0.55
	<i>Pesticides</i>	Glyphosate	kg	454.00
Metazachlor		kg	275.80	17.20
Trifluralin		kg	344.17	17.61
<i>Seeds</i>		<i>B. carinata</i> seeds	kg	5.36
<i>Labour</i>	Farm worker	h	7.30	-

seed, Emilia Romagna, Tuscany, Sicily for carinata and Tuscany and the Marche for sunflower), which could be profitable in Italy (Fig. 2).

Brassica carinata confirmed its well-known rusticity and adaptability to the environmental conditions of many of the tested areas giving good grain yield and good amount of crop residues. These characteristics, linked to the relatively poor input requirements, the good resistance to water stress and to pod shattering, open good application perspectives (Zanetti et al., 2009) for this new non-food oil crop, especially for autumnal sowing in southern European areas. All the crops showed a high seed yield variability within years (data not shown) and among experimental sites (Tab. 4). The statistical analy-

sis due to the high variability of on-farm cultivations of the three randomised sampling highlighted some significant yield differences among oil crops only in the Marche, even if the results obtained in Veneto and Tuscany showed large (but not significant) differences. In Veneto, Emilia Romagna, Tuscany and Sicily, carinata provided grain yields higher than 2.3 t DM ha⁻¹ in open fields. From these results, and considering the NCV value of *B. Carinata* oil, this new crop can be considered a potential additional option for bioenergy production. Further studies are needed to improve the knowledge of the agronomic and genetic aspects of this crop.

The differences in seed oil content among species were significant in many of the experimental sites except for the Marche and Sardinia trials, with sunflower and rapeseed characterised by a higher seed oil concentration if compared to carinata (Tab. 4). On the contrary, seed nitrogen content was generally higher in carinata than rapeseed (Tab. 4).

To define sustainable bioenergy chain as well as to reduce the use of energy during the plant cultivation phase is fundamental the application of low external input cultivation systems. The results of the “Bioenergie” project indicate the possibility of cultivating both conventional (rapeseed and sunflower) and new (carinata) oil crops using low input systems without a significant seed and oil yield reduction in Central and Southern Italy (Tab. 5), confirming the possibility of reducing production costs and environmental impacts.

Unlike 00 rapeseed and sunflower, carinata

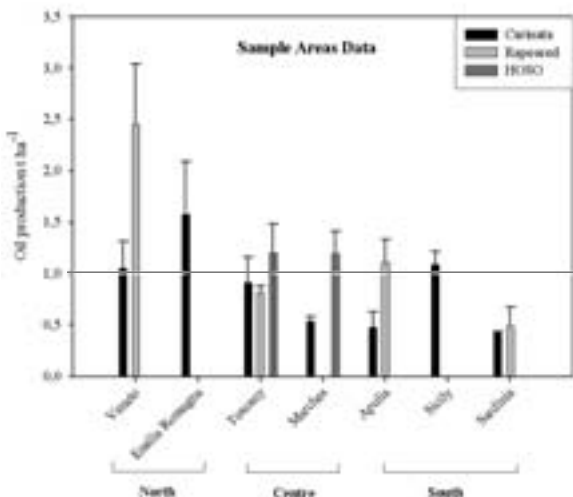


Figure 2. Oil yield of on farm trial of the tested crops. Error bars indicate standard deviation among sample areas.

Table 4. Effect of on-farm trial location on yield components of rapeseed, carinata and sunflower.

Region	Location	Crop +	Seeds				Crop residues		
			Open field yield (t ha ⁻¹ DM)	Sample area yield (t ha ⁻¹ DM)	Oil content (% DM)	N content (% DM)	GLS (mmoles kg ⁻¹ DM)	Yield (t ha ⁻¹ DM)	N content (% DM)
Veneto	Po di	R	4.08	5.38	45.7	3.5	18.6	12.8	nd
	Tramontana (RO)	C	1.75	3.29	31.8	5.0	130.6	20.5	nd
				ns	**	**	**	ns	-
Emilia Romagna	Lugo (RA)	C	2.87	5.53	32.5	5.1	100.1	17.7	0.7
		C	3.10	4.04	33.3	4.8	80.2	10.3	0.5
				ns	ns	*	*	ns	*
Tuscany	Roccastrada (GR)	H	nd	2.61	46.1	3.0	-	4.5	0.8
		C	nd	2.30	39.3	3.8	86.6	8.5	0.4
		R	nd	1.64	49.5	2.5	17.3	6.8	0.5
				ns	**	**	*	ns	
Marches	Recanati (AN)	H	1.86	2.63	45.1	3.8	-	4.8	1.0
		C	1.12	1.00	41.7	3.9	92.4	0.8	0.3
				**	ns	**	-	**	**
Apulia	Gravina di Puglia (BA)	R	1.57	2.32	48.0	3.1	13.5	4.3	0.5
		C	1.43	1.36	35.0	4.8	108.8	4.3	0.6
				ns	**	**	ns	ns	
Sicily	Ispica (RG)	C	2.89	2.91	38.5	4.1	62.4	5.6	0.4
		C	2.59	2.64	40.1	3.6	97.4	3.6	0.4
				ns	ns	ns	**	*	-
Sardinia	Ottana (NU)	R	nd	1.10	45.4	3.1	13.7	6.3	0.3
		C	nd	1.07	39.5	4.1	62.3	10.3	0.4
				ns	ns	*	**	**	ns

+ C stands for *Brassica carinata*; R for rapeseed; H for high oleic sunflower; DM Dry Matter; N Nitrogen; GLs Glucosinolates; nd not determined. * P ≤ 0.05; ** P ≤ 0.01 ns not significant.

defatted seed meals (DSM) can not be used as a feed due to the high level of glucosinolates that causes the well known goitrogen effect (Tab. 4 and 6). All DSMs chemical composition (Tab. 6) makes their application as organic fertilizers interesting, due to the nitrogen level higher than 5% and total phosphorous amount of around 1% (Tab. 6). In addition, the high glucosinolate content makes carinata DSM a base material for the production by a patented procedure (Lazzeri et al., 2007b) of a 100% vegetable amendment able to release in soil biologically active compounds. This technique is called Biofumigation and begins to be applied for natural control of some soil-borne pests and pathogens (Lazzeri et al., 2009; Furlan et al., 2004) and soil fertility management in horticulture production.

DSM incorporation in soil, in addition to fertilising and/or biofumigant properties, can be

considered as a non-food utilisation that permits a significant CO₂ sequestration from the atmosphere as stable humus in soil (Freibauer et al., 2004). This means that, year after year, a local energy chain could activate a virtuous agronomic technique aimed at improving organic matter content in soil, an aspect that, especially in some southern areas, is fundamental for maintaining sufficient soil fertility. A raw balance of the CO₂ sink effect, carried out using the common isohumic coefficient of 30% (Costantini, 2004), shows that the incorporation of 1 t of DSM could potentially sequester in soil around 160 kg ha year⁻¹ of C that means around 0.6 t/ha year⁻¹ of CO₂.

The soil incorporation of crop residues must also be carefully evaluated due to the relevant biomass production from 1 to 20 t ha⁻¹ DM with a N amount ranging from 0.5 to 0.7% (Tab. 4) and considering that straw biomass contains the

Table 5. Effect of on-farm trial location on yield of rapeseed, carinata and sunflower grown under high and low input cultivation techniques.

Region	Crop*	Grain Yield (t ha ⁻¹ DM)			Oil content (% DM)			Oil yield (t ha ⁻¹ DM)		
		HI	LI	Mean	HI	LI	Mean	HI	LI	Mean
Tuscany	C	2.25	2.30	2.27 b	34.5	39.3	36.9 b	0.80	0.94	0.87 b
	R	1.78	1.64	1.71 b	50.3	49.5	49.9 a	0.92	0.83	0.87 b
	H	3.17	2.61	2.89 a	50.6	45.8	48.2 a	1.72	1.26	1.49 a
	Species	**	**	**						
	Input	Ns	Ns	Ns						
	Species x Input	Ns	**	Ns						
Marches	C	1.28	1.00	1.13	42.3	41.7	42.0	0.55	0.42	0.49
	H	2.80	2.63	2.71	42.5	45.3	43.9	1.21	1.21	1.21
	Species	**	Ns	**						
	Input	Ns	Ns	Ns						
	Species x Input	Ns	Ns	Ns						
Apulia	C	1.60	1.36	1.48	38.3	35.0	36.6	0.61	0.47	0.54
	R	2.27	2.32	2.29	44.6	48.0	46.3	1.01	1.11	1.06
	Species	**	**	**						
	Input	Ns	Ns	Ns						
	Species x Input	Ns	**	Ns						

* C stands for Brassica carinata; R for rapeseed; H for high oleic sunflower. DM Dry Matter; HI high input cultivation techniques; LI low input cultivation techniques.

** P ≤ 0.01 ns not significant.

higher amount of carbon in oil crops (Gan et al., 2009). This could permit a sequestration of more than 300 kg of CO₂ for each ton of biomass incorporated in soil, calculated using the isohumic coefficient of 15%.

Finally, the evaluation of the energy and environmental balances expressed as CO₂ equivalents of the cultivation of carinata in four different localities is reported in Table 7. Seed oil content, needed for biodiesel yield evaluation, was 32.5% in Budrio, 35.0% in Gravina, 41.5% in S. Piero a Grado and 31.8% in Po di Tramontana. NCV resulted 37.66 MJ kg⁻¹ for *B. carinata* oil and 18.19 MJ kg⁻¹ for *B. carinata* DSM. The values in the last column of the Table 7 reports the CO₂eq emission considering the two

co-products with an equal relevance, and obtained taking into account of a loss of 2% with respect to the grain quantity. The 2% of mass losses is a value measured after oil extraction in the plant used in the project.

The results clearly show how Po di Tramontana trial presents a higher value of needed Energy during process (En/S) when compared to the other sites where low input cultivation techniques had been applied. As a consequence, referring to a MJ of biodiesel, energy efficiency (expressed as obtained energy / needed energy) is in this case lower than one, while in the other three environments it is higher than 1.3.

CO₂eq standard emissions for carinata are not present in the EU Dir 2009/28/EC (Annex

Table 6. Chemical composition of defatted seed meals (DSM) from rapeseed, sunflower and carinata.

		Moisture %	Oil content % DM	N content % DM	Total P content % DM	Organic C % DM	Glucosinolates (mmoles kg ⁻¹ DM)
Carinata	Mean	4.9	11.0	5.5	0.9	34.6	95.9
	SD	0.9	1.5	0.3	0.1	0.8	5.5
HOSO	Mean	5.7	12.0	5.0	0.8	35.1	Absent
	SD	1.2	1.3	0.2	0.1	1.0	
Rapeseed	Mean	7.2	13.4	4.9	0.8	34.4	25.1
	SD	1.5	1.4	0.3	0.1	1.2	2.0

DM = Dry Matter; C = Carbon; P = Phosphorus.

Table 7. Energy requirements and GHG emissions as CO₂ equivalent.

Locality	Yield (DM)		En/S		En/P		Eo/En		CO ₂ eq/S kg CO ₂ eq ha ⁻¹	CO ₂ eq/P kg CO ₂ eq kg ⁻¹	CO ₂ eq/MJ g CO ₂ eq MJ ⁻¹	CO ₂ eq/MJ g CO ₂ eq MJ ⁻¹
	Grain kg ha ⁻¹	Biodiesel kg ha ⁻¹	MJ ha ⁻¹	Grain MJ kg ⁻¹	Biodiesel MJ kg ⁻¹	Grain MJ MJ ⁻¹	Biodiesel MJ MJ ⁻¹					
Budrio	1700	357	9496	5.59	26.62	4.01	1.39	609	0.36	46	10.12	
Gravina in Puglia	1400	328	6939	4.96	21.16	4.61	1.75	424	0.30	35	8.56	
San Piero a Grado	1840	548	9417	5.12	17.19	4.71	2.15	738	0.40	36	11.33	
Po di Tramontana	1730	351	20311	11.74	57.83	1.89	0.64	1271	0.73	98	20.76	

DM = Dry Matter; En = needed Energy; Eo = obtained Energy; S = surface; P = product.

* CO₂eq emission considering biodiesel the unique useful product of the process.

** CO₂eq emission considering the oilcake as useful co-product of biodiesel and a total mass loss of 2%.

V part D) and for comparison the value of rape-seed has been assumed. For this crop, the CO₂eq emissions for the production of one MJ of biodiesel related to the cultivation phase is 29 gCO₂eq/MJ. Considering biodiesel as the unique useful product of the process, in no case CO₂eq emissions resulted lower than the reference value. On the contrary, considering as useful outputs also DSM as co-product of oil extraction, the CO₂eq cultivation-phase emissions for a MJ of biodiesel were widely lower than the limits reported by in the Dir. 2009/28/EC.

Note how the better performances in balances among low input treatments was obtained in Gravina trial due to lower inputs applied in Apulia, although San Piero yield and oil content resulted higher.

The “Bioenergie” project was presented and discussed in more than thirty demonstrative meetings carried out at National level. Its proposal could represent a potential sustainable opportunity for the entire agricultural system of the Mediterranean basin. The results highlight the possibility of improving the sustainability of bioenergy chains in many Italian region adopting low external input cropping systems, choosing the right crop and valorising oil crop product and co-product at local level.

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