BIO-FUEL FROM SUNFLOWER IN CENTRAL ITALY: FARMING SYSTEM INFLUENCE ON YIELDS, OIL QUALITY AND ENERGETIC BALANCE

BIO-FUEL FROM PURE SUNFLOWER OIL IN CENTRAL ITALY: FARMING SYSTEM INFLUENCE ON YIELDS, OIL QUALITY AND ENERGETIC BALANCE.

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ABSTRACT: The research aimed at investigating the influence of different farming managements on sunflower oil production in terms of oil yields and technological quality to be used in purity as bio-fuel, and at understanding the possibility to reduce agricultural inputs to maximize the energetic balance. Two experimental fields were carried out by comparing two farming systems, three different fertilization levels and four sunflower varieties. Conventional farming gave a higher seed yield. Low oleic varieties resulted more productive than high oleic varieties in both farming management. Also nitrogen positively affected the yield, especially under conventional management. However, in spite of a difference in yield, input/output energetic analysis highlighted a less evident difference between conventional and organic management, especially if correlated to the highest level of nitrogen. Mechanically extracted oil percentage was higher under organic conditions. Fertilization levels and farming managements did not affect oil composition. The research confirms the highest productive potential of conventional farming, even if it is possible to affirm that the reduction of inputs and the use of alternative crop managements permit to save a significant amount of energy, without negatively affecting crop performances. Moreover, some agricultural inputs, as nitrogen mineral fertilizers, seem to reduce fruit oil content.

Keywords: sunflower, liquid biofuels, agro-energy farm

1. INTRODUCTION

The paper reports the results of a research, inserted in the project "Pure Vegetable Oil as Bio-carburant" funded by the Province of Florence, aimed at investigating the influence of different farming managements on sunflower oil production in terms of oil yields and technological quality to be used in purity as bio-fuel. Moreover, considering that an energetic crop to be competitive must provide a positive energy return, part of the research focused on the understanding the possibility to reduce agricultural inputs in order to maximize the energetic ratio.

Biomass energetic utilisation is today of strategic importance in relation to a significant reduction of GHG and other gas emissions [1] [2] [3] and to environment and rural sector safeguard. In fact, energetic crop exploitation is strongly linked not only to energetic benefits but also to positive externalities in favour of pollution reduction, soil conservation, rural development and employment [4] [5]. Therefore biomass assumes a strategic role since it is a renewable, clean, versatile resource and, by means of specific conversion technologies, can partially replace fossil fuels [6].

Today energetic crops represent an interesting alternative to food crops in different agricultural area of Italy, especially in relation to the new European scenarios. Vegetable oils can be used as fuel in diesel engine, both as pure oil or previously converted in bio-diesel.

Regarding the use of PVO (Pure Vegetable Oil) in diesel-modified engines, this special energy use represents, rather than bio-diesel, an opportunity for the European farmers. The entire chain of production of this bio-fuel can be in fact considered a real bio-fuel short chain: starting from the crop cultivation, the mechanical extraction of oil from the seeds and the direct use in modified diesel engines allow the farmers to produce themselves the fuel without the influence of any industry. The engine conversion technology is actually well known and set up for the use of pure rapeseed oil [7] [8]. The first RK standard for PVO use have been created for the rapeseed oil (Fig. 1).

TUM / LANDTECHNIK WEIHENSTEPHAN	LTV-Work-Session on Decentral Vegetable Oil Production, Weihenstephan Quality Standard for Rapeseed Oil as a Fuel (RK-Qualitätsstandard) 05/2000			In Cooperation with: A S G
Properties / Contents	**Unit**	**Limiting Value min.**	**max.**	**Testing Method**
charcteristic properties for Rapeseed Oil				
Density (15 °C)	kg/m³	900	930	DIN EN ISO 3675 DIN EN ISO 12185
Flash Point by P.-M.	°C	220		DIN EN 22719
Calorific Value	kJ/kg	35000		DIN 51900-3
Kinematic Viscosity (40 °C)	mm²/s		38	DIN EN ISO 3104
Low Temperature Behaviour				Rotational Viscometer (testing conditions will be developed)
Cetane Number				Testing method will be reviewed
Carbon Residue	Mass-%		0.40	DIN EN ISO 10370
Iodine Number	g/100 g	100	120	DIN 53241-1
Sulphur Content	mg/kg		20	ASTM D5453-93
variable properties				
Contamination	mg/kg		25	DIN EN 12662
Acid Value	mg KOH/g		2,0	DIN EN ISO 660
Oxidation Stability (110 °C)	h	5.0		ISO 6886
Phosphorus Content	mg/kg		15	ASTM D3231-99
Ash Content	Mass-%		0.01	DIN EN ISO 6245
Water Content	Mass-%		0.075	pr EN ISO 12937

Figure 1: Quality Standard norm for rapeseed oil as fuel

For many technical parameters the PVO is similar to the diesel but for some of them the differences are relevant; for example the density, the cinematic viscosity and the acidity of PVO are greater than diesel.

For these reasons the engines need to be modified in some parts and, during the project implementation, this part was developed from the German partner VWP (Vereinigte Werkstätten für Pflanzenöltechnologie, Allersberg, Germany), the owner of this conversion patent.

Actually rapeseed crop is mostly cultivated in the northern part of Europe and it represent the bigger vegetable oil source for this EU area, but it is less suitable for the Italian environment, mainly because of the lack of rainfall compared with the north Europe areas.

On the contrary, sunflower is one of the most important oilseed cops, especially in southern European countries. In Italy, sunflower is mainly cultivated in the central part of the country, where more than 75% of sunflower cultivation area is located. Sunflower is commonly cultivated under rainfed conditions, in clay loam soils and inserted in rotation with winter cereals.

Unfortunately the technical properties of conventional sunflower oil are different from the rapeseed oil in relation with the RK standard, mainly due to the high iodine number (Table I). The iodine number is a direct measure of the number of double bonds along the fatty acid carbon chain, representing a measure of the degree of oil unsaturation. Obviously it is strictly related with the oil fatty acid composition.

The technological quality of the sunflower oil for non-food application is a direct function of the amount of oleic acid (C18:1) and linoleic acid (C18:2) that together represents the 85-90% of the entire fraction of fatty acids. The percentage of oleic acid in conventional varieties of sunflower is around 20-30% while the linoleic acid percentage is around 70%. This ratio leads to a high iodine number due to the two double bonds of the linoleic acid.

Table I: Technical characteristics of PVO, diesel and bio-diesel

Properties	unit	Rk-Std[1]	CSO[2]	HOSO[3]	BHOSO[4]	RO[5]	DF[6]
Density (15°C)	Kg/m3	900 - 930	914	919*	886	920	820,6
Flash Point	°C	220	274	240*	182	246	72
Low Calorific Value (LCV)	kJ/kg	35000	37100	37100**	39900	37400	42700
Cinematic Viscosity (40°C)	mm2/sec	38	37,1	33,6*	4,5	37	2,7
Cetane no.	-	-	37	37**	57,8	32-37,6	>45
Carbon residue	% m/m	0,40	0,01	<1*	-	0,32	-
Iodine no.	g/100g	100 - 120	110-140	115*	100	94-120	-
Sulfur	mg/kg	20	0,03	<0,001*	-	0,03	0,36

[1] Rk Std: Standard RK for rapeseed; [2] CSO: Conventional Sunflower Oil; [3] HOSO: High Oleic Sunflower Oil; [4] BHOSO. Biodiesel from High Oleic Sunflower Oil; [5] RO:Rapeseed Oil; [6] DF: Diesel Fuel

Seeds of a special type of sunflower varieties, named High Oleic (HO), are significantly rich in oleic acid (70-90% of total fatty acid content).

The high oleic sunflower varieties are the most suitable for PVO bio-fuel purposes since the characteristics of their oil, containing more than the 80% of oleic acid, fit the RK quality standards referred to rapeseed oil.

The oleic acid content and the related unsaturation degree of the oil of the HO sunflower varieties seem also influenced by cropping techniques and environmental conditions [9]. In particular the percentage and ratio of the two main fatty acids (oleic and linoleic) are strongly affected by the climate and the environment. Their biosynthesis is mainly controlled by the temperature level during seed development physiological phase. In general, high temperatures promote the production of oleic acid, while low temperatures lead to the production of linoleic acid [10] [11]. This is mainly due to the activity of the group of desaturase enzymes; the Δ-9 desaturase that converts the stearic acid into oleic acid, and the Δ-12 desaturase that converts the oleic acid into linoleic [12]. Low temperatures enhance the Δ-12 desaturase enzyme activity; therefore the oleic acid produced turns into the linoleic acid.

In the HO varieties the Δ-12 desaturase enzyme is only active during the first days of embryo development [13]. Moreover in the HO varieties the oleic/linoleic ratio can be influenced by the temperature, and due to the existence of a parallel metabolic way for the linoleic-oleic acid conversion, even if this pathway seems to be less efficient [13].

[14] in a long experimentation demonstrates that more than 95% of the existing variability related to the qualitative characters (fatty acid composition) between 10 different sowing times is due to the differences of minimal temperature during the period between flowering and physiological maturation, concluding that in central Italy the oleic acid percentage decreases with the delay in sowing. However [15] observed an opposite behaviour.

Very interesting appears the possibility to obtain oil with a high content of oleic acid sowing at the end of winter season without a significative yield reduction in suitable environments (e.g. South Italy, Portugal, Greece, North-African Countries).

Regarding the influence of nitrogen fertilisation on the HO sunflower varieties oil composition, only few scientific works are available. [16] did not find significative differences in oleic acid percentages in high oleic sunflower cultivars.

In spite of the lack of scientific articles related with the agronomical experimentation on HO sunflower varieties focused on the production of PVO and its direct use as bio-fuel, the research aimed at investigating the role of the main factors affecting the sunflower production in central Italy, such as:

1) Develop a first varietal screening for the PVO bio-fuel chain;
2) Evaluate the influence of fertilisation on PVO technological properties;
3) Investigate crop environmental sustainability in different cropping systems (organic and conventional).

2. MATERIALS AND METHODS

The agricultural investigation was carried out in collaboration with the farms Buonamici and Mondeggi located in the Province of Florence, where two experimental fields were implemented in the cropping season 2006 by considering the following factors: two farming systems, conventional in the farm Mondeggi and organic in the farm Buonamici; three different level of fertilisation; four sunflower varieties, two high oleic varieties (Trisun 860 and PR64H41) and two low oleic varieties (Sanbro and Floralie). The trial was organised in a split-split-plot experimental design with three replications considering the farming management as the first main factor and the fertilisation level as the second main factor. Each experimental field covered an area of about four hectares. A framework of crop management is reported in table II. The fertilisation was carried out by distributing the following fertilisers: urea, ammonium nitrate, triple perphosphate and potassium sulphate in conventional farm, and borlanda Prodigy (sugar-beet residues) in organic farm.

Table II: Crop management

	Farm					
	Conventional			*Organic*		
Area (ha)	4			3.5		
Previous crop	Set aside			Set aside		
Fertilisation (kg/ha)						
	Control	Level I	Level II	Control	Level I	Level II
N	0	50	100	0	30	70
P_2O_5	0	30	60	0		
K_2O	0	30	60	0		
Soil preparation	Ploughing - Harrowing			Ploughing - Harrowing		
Sowing						
Date	17-05-06			05-05-06		
Plant density (p/m^2)	15			15		
Weed control	Chemical at sowing time			Hoeing		
Harvest	05-10-06			25-09-06		

Experimental trials were monitored following plant growth by measuring the following parameters: Plant Height (PH), Leaf Number (LN), Stem Diameter (SD), Inflorescence Diameter (ID), Plant Dry Weight (PDW), Plant Seed Yield (PSY) and Plant Oil Yield (POY). Dry weights were measured after a treatment in an oven at 105°C for 72 hours. During crop cycle, plants were monitored by checking plant density, pest and disease attacks and weed presence.

The oil content of sunflower seed samples was detected using a Soxhlet extractor. The extraction was carried out starting from a milled seed sample. The oil composition data were obtained by means of a gas-chromatograph. The oil content of each full-field sunflower plot was determined by means of a screw press.

Statistical analysis was performed as a mix model, considering fertilisation as the random factor. Bonferroni test was performed to evaluate the variability between average values for each variation source. The correlation matrix was obtained by means of Pearson correlation procedure.

Energetic balance calculation

Crop energetic balance was calculated for each experimental trial taking into account the different sources of variation by means of a quantification of inputs and outputs [17] [18]. In the calculation, the energetic costs relating to the construction of agricultural machine recovery buildings were not considered. The energetic flux attributed to each agricultural practice was calculated on the basis of the following direct and indirect costs: fuel, lubricant, product utilised (fertiliser, seed, etc.), energetic cost amortization of agricultural machines and of manpower [19]. In order to calculate the amortisation values, was utilised the energetic cost coefficient per weight unity and work hour obtained from the ratio between the energetic cost of a brand new machine plus the cost of maintenance and repairing and its technical life duration [20].

3. RESULTS

Only the most significative results are reported below.

In both localities, plants showed a regular development without significant difference between farming management. The highest fertilisation level determined a more pronounced growth in height, with the variety Sanbro raising the highest value (about 160 cm) at the end of crop cycle.

A different trend was observed in inflorescence diameter. At *Mondeggi* farm, no differences were detected between varieties, with values ranging from 24.5 to 26 cm. On the contrary, at *Buonamici* farm the development of inflorescences was significantly different between varieties: the two low oleic varieties arose average values of 31 cm, while the two high oleic varieties showed inflorescences of 25 cm. Level of fertilisation did not affect this variable.

Total dry biomass was affected by farming management. Plants grown under organic system showed in general a lower biomass, around 500 g per plant for the varieties Floralie, PR84H41 and Sanbro and 310 g per plant for the variety Trisun 860. Under conventional management, plants arose a total dry biomass range of 470-590 g: Sanbro variety reached the highest value, while Trisun 860 the lowest. No difference were detected between the fertilisation level I and II, while the control level showed four each variety a reduction of about 25 g per plant.

In tables III and IV are summarised the results concerning seed and oil yields per hectare.

Table III: Seed yield (t/ha)

Farm	Variety	Seed Yield (ton/ha)		
		Level II	Level I	Control
Conventional	Floralie	1,5 b	1.2 b	0,9 ab
	PR64H41	1.3 b	1,0 bc	0,8 b
	Trisun 860	1,0 c	0,8 c	0,8 b
	Sanbro	1,8 a	1,5 a	1,1 a
Average		1,4	1,1	0,9
Organic	Floralie	1,3 a	1,1 a	0.8 ns
	PR64H41	1.0 b	0.8 b	0.6 ns
	Trisun 860	0,9 b	0,7 b	0,6 ns
	Sanbro	1.2 ab	0.9 ab	0,7 ns
Average		1,1	0,9	0,7

For each column means followed by a common letter are not significantly different at the 5 % level. ** = F test significant at 1% level, * F = test significant at 5% level, ns = F test not significant

Table IV: Oil yield (kg/ha)

Farm	Variety	Oil Yield (kg/ha)[1]		
		Level II	Level I	Control
Conventional	Floralie	518,1 b	434,5 b	315.0 ab
	PR64H41	462.7 b	354.4 bc	280.0 b
	Trisun 860	362.0 c	277.8 c	280.0 b
	Sanbro	637.9 a	541.5 a	385.0 a
Average		495.2	402.1	315.0
Organic	Floralie	440.0 a	389.0 a	280.0 ns
	PR64H41	359,4 b	271,0 b	210,0 ns
	Trisun 860	306.6 b	256.8 b	210.0 ns
	Sanbro	410.0 ab	314.5 ab	245.0 ns
Average		379,0	307,8	236,3

[1] Oil yield was calculated considering an average oil content percentage of 33.3% for Mondeggi farm and 35.5% for Buonamici farm

For each column means followed by a common letter are not significantly different at the 5 % level. ** = F test significant at 1% level, * F = test significant at 5% level, ns = F test not significant

Farming management significantly affected final yield. Conventional farming gave a seed yield up to 20% higher than the yield registered under organic management, with an average difference of 0.3 ton/ha. The two low oleic varieties (Sanbro and Floralie) resulted more productive than the two high oleic varieties (Trisun 860 and PR64H41) in both farming management: variety Sanbro gave the highest yield (1.8 ton/ha) under conventional management, variety Floralie in the organic farm (1.3 ton/ha). Also nitrogen positively affected yield. A more pronounced gap was registered in conventional farm, especially regarding the highest fertilisation level and the other two, whilst, under the organic management, the within-variety differences arose the same level between the three level of fertilisation. However experimental yields, both under conventional and organic management, were significantly lower than average yields reported in previous studies.

No significative variety difference was detected on oil content rate: the percentage of oil chemically and mechanically extracted from achenes arose an average value of respectively 44% and 35%. A little but significant difference was recorded between farms: the percentage of mechanically extracted oil was higher (2.2%) in sunflower produced under organic management.

Oil composition showed different level of significativity in function of farm management, varieties and levels of fertilisation, as summarised in table V. The two principal fat acids, oleic and linoleic, resulted only affected, as foreseen, by variety, while no effect was detected for fertilisation level and farm management. Variety affected also the other minor fat acids. Farm management also affected stearic and erucic acids, both increased under organic farming. The interaction between farm management and variety resulted only significant for the arachidic and erucic acids. In general under the organic management we observed a greater accumulation of these two acids (Figure 2), even if variety Trisun 860 and Sanbro showed an opposite trend respectively for arachidic and erucic acids.

Table V: Fatty acid oil composition (%)

Variety	Farm						
	Organic						
	Palmitic	Stearic	Oleic	Linoleic	Arachidic	Erucic	Other
Floralie	4.43	3.55	33.67	56.94	0.25	0.74	0.43
PR64H41	3.54	4.23	81.26	9.11	0.32	1.01	0.54
Trisun S60	3.20	3.42	88.14	3.56	0.19	0.96	0.54
Sanbro	4.88	4.26	38.54	50.50	0.24	0.99	0.60
	Conventional						
	Palmitic	Stearic	Oleic	Linoleic	Arachidic	Erucic	Other
Floralie	4.33	3.49	36.89	54.09	0.14	0.62	0.44
PR64H41	3.58	2.80	87.70	5.17	0.27	0.88	0.60
Trisun S60	3.51	3.04	89.97	1.71	0.25	0.82	0.69
Sanbro	4.78	4.31	38.10	51.00	0.23	1.00	0.58

	Palmitic	Stearic	Oleic	Linoleic	Arachidic	Erucic	Other
Farming system (F)	ns	**	ns	ns	ns	**	ns
Variety (V)	**	**	**	**	**	**	**
F x V	ns	ns	ns	ns	**	**	ns
Nitrogen (N) [Farm]	ns	ns	ns	ns	ns	ns	ns
V x N [Farm]	ns	ns	ns	ns	ns	ns	ns

** F-test significant at $p < 0.01$; * F-test significant at $p < 0.05$; ns F-test not significant

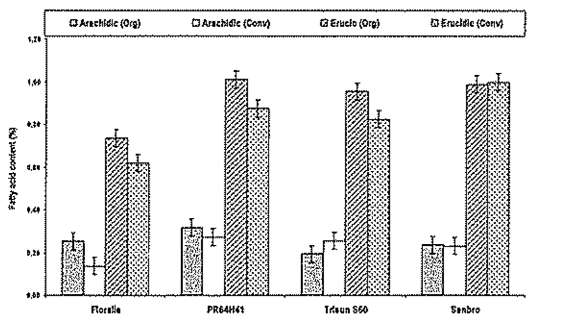

Figure 2: Arachidic and erucic acid content (%) under conventional and organic management

The results of output/input balance are summarised in table VI.

Total energetic cost referring to farming, transport and extraction resulted significantly variable between field managements (conventional and organic) and between fertilisation levels as well. Under conventional farming and with the highest level of fertilisation, total inputs arose a value of 20.2 GJ/ha; for the other level of fertilisation the reduction in the energetic cost is simply linked to the energetic cost of fertilisation and relative quantities of fertilisers.

Specifically, the two low oleic varieties (Sanbro and Floralie) reached interesting output/input ratios compared with the HO varieties also in presence of a reduced level of fertilisation. For the high oleic variety Trisun 860 under conventional farming system no differences were detected between the highest level of fertilisation and the control, and the output/input ratio obtained with the level I resulted lower than the control. The differences detected in organic farm are less pronounced in function of fertilisation level.

Table VI: Energetic balance

			Conventional						Organic					
			Level II		Level I		Control		Level II		Level I		Control	
			GJ/ha	%	GJ/ha	%	GJ/ha	%	GJ/ha	%	GJ/ha	%	GJ/ha	%
Tillage			6.9	34.2	6.9	38.6	6.9	45.2	6.6	41.4	6.6	42.3	6.6	44.0
Fertilisation			4.9	24.4	2.6	14.7	-	-	0.9	5.8	0.6	3.8	-	-
Sowing & weeding			2.9	14.5	2.9	16.4	2.9	19.2	0.9	5.6	0.9	5.7	0.9	5.9
Hoeing			-	-	-	-	-	-	1.3	8.3	1.3	8.3	1.3	8.8
Harvest & transport			4.2	21.0	4.2	23.7	4.2	27.8	5.0	31.4	5.0	32.1	5.0	33.4
Extraction			1.2	5.8	1.2	6.6	1.2	7.7	1.2	7.4	1.2	7.6	1.2	7.9
Total Input		Oil	7.1		6.3		5.4		5.6		5.5		5.3	
		Cake	13.1		11.6		9.9		10.3		10.1		9.7	
		Total	20.2	100.0	17.9	100.0	15.3	100.0	15.9	100.0	15.6	100.0	15.0	100.0
Potential Output		Oil	18.4		14.9		11.7		14.1		11.4		8.8	
		Cake	20.5		16.7		13.0		15.7		12.7		9.8	
		Total	38.9		31.6		24.7		29.8		24.2		18.5	
Output/Input	Within variety	Oil	2.6		2.4		2.2		2.5		2.1		1.7	
		Cake	1.6		1.4		1.3		1.5		1.3		1.0	
		Total	1.9		1.8		1.6		1.9		1.6		1.2	
	Floralie	Oil	2.7		2.6		2.2		2.9		2.6		2.0	
		Cake	1.6		1.5		1.3		1.8		1.6		1.2	
		Total	2.0		1.9		1.6		2.2		2.0		1.5	
	PR64H41	Oil	2.6		2.1		1.9		2.4		1.8		1.5	
		Cake	1.5		1.3		1.2		1.4		1.3		0.9	
		Total	1.8		1.6		1.4		1.8		1.4		1.1	
	Trisun 860	Oil	1.9		1.6		1.9		2.0		1.7		1.3	
		Cake	1.1		1.0		1.2		1.2		1.1		0.9	
		Total	1.4		1.2		1.4		1.5		1.3		1.1	
	Sanbro	Oil	3.3		3.2		2.7		2.7		2.1		1.7	
		Cake	2.0		1.9		1.6		1.6		1.3		1.0	
		Total	2.5		2.4		2.0		2.0		1.6		1.3	

Potential output was calculated multiplying oil and cake production for the relative LHV (37.1 MJ/kg and 22.3 MJ/Kg)

4. DISCUSSION AND CONCLUSIONS

The experimental trials highlighted some interesting aspects that need to be investigated.

The organic cropping system, in spite of a reduction in seed yield, leads to a slightly higher oil content confirming the great adaptability of the sunflower crop to low-input farming systems as reported in previous studies [21] [22].

Moreover farming system do not affect the oil quality in terms of oleic (C18:1) and linoleic acid (C18:2), not influencing probably the iodine number. Despite farming system influence on stearic (C18:0) and erucic (C22:1) acid content, the total amount of these acids, given their low percentage, do not affect total iodine number. Therefore the agricultural system does not appear to be significantly important for the PVO technical quality (iodine number).

Nitrogen fertilisation, especially under the conventional farming system, enhances crop performance, but this yield improvement has to be evaluated taking carefully into account the environmental cost and the energetic output/input balance.

In fact, even if the experimental yields resulted not so excellent, energetic output was always higher than energetic input under every experimental condition.

However, the energetic analysis of input and output highlighted that, in spite of a significant difference in yield, the difference between conventional and organic management is less evident (around 2%), especially if correlated to the high level of nitrogen. This result is agreement with [21] that showed that in Italy a high energy balance (5:1) was obtained under low input farming management.
For the future, it is clear from the present experimentation that with a correct management of the organic farming system (e.g. applying correct crop rotation techniques) it will be possible to exploit the ability of sunflower crop to utilize the residual nitrogen fertility in order to maximize the seed and oil yield in an environmentally sustainable way.

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