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Yield, Water Use Efficincy and Biodesel Production of Some Oil Crops Irrigated with Treated Wastewater in Two Soil Types

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Abstract: Oil crops could be employeed as food or energy crops. Due to water scarece and using alternative sources of water like treatead wastewater (TWW) energy crops could be irrigated with TWW as non food crops. Field trials were conducted in winter and summer seasons in two soil types, clay and sandy soils. The trials aimed to evaluate yield,water use efficincy and biodesel production of three oil crops viz., soybean, sunflower and canola irrigated with TWW. Water requirements varied according to crop and season where the mean wastewater irrigation quantities recorded were 6034 m^3 ha^{-1}, 6792and 7638 m^3 ha^{-1} for soybean, canola and sunflower, respectively. There were significant increases in seed yield, straw and biological yields due to soil type for all oil crops used. Biodesel yields of canola was the higest among the three crops and was 0,500 and 5.05 t ha^{-1} on sandy and and clay soils, respectively. Seed analysis indicated that the ranges of heavy metals were within the normal ranges expected and were far below levels that would be of concern due to the high pH of both sites. It could be concluded from this study that the yields achieved were proportionately increased more on the in clay soil than at sandy soil where nutrient demand would be greatest. It could be concluded from this study that using energy crops as biofuel as a sustainable substitute for petroleum diesel is a timely vital solution to the inescapable global issues related to environmental pollution and fossil fuel.

Key words: Canola · Soybean · Sunflower · Wastewater · Water productivity · Yields · Biodesel · Heavy metals

INTRODUCTION

The secondary treated wastewater STWW generated from Greater Cairo is about 1.85 million m^3 day^{-1} and it is estimated that the generated treated wastewater TWW will eventually reach up to 5.5 million m^3 day^{-1} by the year 2050. From environmental point of view such quantities should be disposed off safely. Under limited water resources and drought conditions wastewater has been used to support the agricultural production in many countries such as USA, Germany, India, Kuwait, Saudi Arabia, Oman, Jordan and Tunisia [1]. Several investigators indicated the beneficial role of wastewater in increasing crop yields without or with minimal risks to the plant, soil, groundwater and health [2-7]. One of the most recognized benefits of wastewater use in agriculture is the associated decrease in pressure on freshwater sources. Thus, wastewater serves as an alternative irrigation source [8], especially for agriculture, the greatest global water user, which consumes 70% of available water TWW provides a promising, unconventional water source for irrigation in Egypt [9]. Furthermore, wastewater reuse increases agricultural production in regions experiencing water shortages, thus contributing to food safety [10]. Depending on the nutrients, wastewater may be a potential source of macro- (N, P, K, Ca, Mg, B and Mg) and micronutrients (, Fe, Mn or Zn) [11-12]. Indeed, wastewater reuse has been proven to improve crop yield [12-13] and result in the reduced use of fertilizers in agriculture [14]. However, under Egyptian conditions

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many restrictions have been adopted on wastewater reuse and it is only permitted for wooden trees production. Since oil crops production is considered very important to Egypt and it needs processing before consumption, they may fit irrigation with secondary treated wastewater TWW and benefit from the nutrient additions of wastewater.

The use of biofuel as a sustainable substitute for petroleum diesel is a timely vital solution to the inescapable global issues related to environmental pollution and fossil fuel. Implementing biofuel is considered crucial for both economic and ecological reasons and has gained significant attention. Biodiesel is derived from lipids such as edible or non-edible oils reacting with alcohol with a catalyst [15]. Biodiesel, which is considered clean and environmentally friendly, could be produced from edible oils such as coconut, palm, olive and sunflower oil and non-edible oils such as rubber seed oil and algal oil using a process known as transesterification [16].

Several researchers have previously studied biodiesel production from fresh canola oil [17-19]. The major fatty acid of soybean oil is considered Linoleic acid based on the experimental analysis [20]. In short, biodiesel has attracted much attention due to its various environmental benefits. However, the main challenges include its production cost and availability of suitable raw materials. Edible oil source as a raw material for biodiesel production is not encouraging due to demand for food and the prices increase eventually.

Therefore, the aim of this work is to evaluate the effect of oil crops irrigation methods with secondary treated wastewater TWW on yield, quality, water productivity and heavy metal content. Under two types of Egyptian soils.

MATERIALS AND METHODS

Two field trials were carried out in winter and summer seasons of 2022 and winter 2022/23 seasons in two sites located about 20 km north east of Cairo; Gabal El Asfar farm (clay soil) and El Berka site (sandy soil). The trials aimed to evaluate yield,water use efficincy and Biodesel production of three oil crops viz.,soybean, sunflower and canola irrigated with TWW. The area of each trial the was 2.5 feddans (1.1 hectars) close to the new Gabal El- Asfar wastewater treatment plant and the soil could be classified as clay soil. The same area was chosen in the second site and located inside El-Berka wastewater treatment plant, the soil is gravelly sand and could be classified as sandy soil (Table 1).The chemical analysis of each soil presented in Table (1).

This work was carried out in two sites using all the facilities installed by the project "Cairo East Bank Wastewater Re-use Study", the client is the Cairo Wastewater Organuzation (CWO) and the study is partially funded by the Kuwait Fund for Arab Economic Development (KFAED). After completing the study the facilities (irrigation networks, equipment) were used in this study. Both experimental sites were cultivated using fixed tine-harrow, then leveling was carried out. The experiment was arranged as Complete Randomized block Design(CRBD) in each soil type. Drip irrigation was employeed in both soils. The drip irrigation network included (1) Control head: It is located at the water source supply. It consists of centrifugal pump 4`` /4``, driven by diesel engine (pump QRM charge of 100 m^3 h^{-1} and 50 m lift), sand media filter 48`` (two tanks), screen filter 2`` (120 mesh) back flow prevention device, pressure regulator, pressure gauges, flow-meter, control (2) Main line: PVC pipes of 125 mm in diameter (OD) to convey the

Table 1: General chemical quality of soil at clay and sandy soil sites (Means to 30 cm depth).

Value	PH	EC (dS/m)	HCO_3 (meq/l)	OM (%)	CEC (meq/100g)	NO_3 (mg/kg)	N (mg/kg)	P (mg/kg)	K (mg/kg)
Clay soil									
Mean	6.87	0.27	0.74	4.29	34.5	106	2826	1737	1996
Min.	6.34	0.17	0.40	0.47	12.8	52	1120	812	1200
Max.	7.26	0.38	1.25	7.54	64.9	290	4480	2602	3080
CV%	3.70	22.5	39.6	46.30	47.0	59	40	30	26
Sandy soil									
Mean	8.16	0.79	0.98	0.79	13.4	24	901	229	1506
Min.	7.69	0.21	0.65	0.19	5.5	5	140	92	900
Max.	8.69	2.40	1.35	1.13	25.8	125	2100	343	2350
CV%	3.10	81.10	20.3	37.9	42.8	124	60	33	29

water from the source to the main control points in the field. (3) Sub-main lines: PVC pipes of 75 mm diameter (OD) were connected to with the main line through a control unit consists of a 2`` ball valve and pressure gauges. (4) Manifold lines: PVC pipes of 40 mm in diameter (OD) were connected to the sub main line through control valves 1.5``. (5) Emitters: These emitters Built in (GR) dripper from Polyethylene (PE) tubes 16 mm in diameter (OD) and 50 m in long (emitter QRM charge of 4 lph at 1.0 bar operating pressure, 0.3 m spacing between emitters, 1.0 m spacing between lateral lines.

Canola seeds (Pactol variety) were grown, soybean (Giza 82) variety and and sunflower (Giza4) were planted in sandy and clay soils. The irrigation water was measured by water meter for each plot. Fertilizers were applied according to the normal recommended rates in Egypt. Nitrogen, phosphorus and potassium were applied as ammonium nitrate (33.5% N), calcium super phosphate (15.5% P_2O_5) and potassium sulphate (48% K_2O), respectively. Samples of treated wastewater TWW from clay soil and sandy soil were taken during crop cycle and analysed for a range of agronomic parameters. Nutrient and heavy metal loading rates to field trials were calculated according to the irrigation quantities applied to each crop. Treated wastewater TWWs were analyzed according to [21]. Crop yields were determined, seed, biodesel nutrient and heavy metal content were determined by [22,23].

Biodesel Yield: Oil yield (kg ha^{-1}) was calculated by seed yield (kg fed^{-1}) × seed oil content (%). Seed oil %: was determined by Soxhlet apparatus using petroleum ether (40°C - 60°C b.p) according to [22].

Water Productivity of Oil Crops Seed: $WP_{sunflower}$, WP_{canola} and $WP_{soybean}$ are indicators of effectiveness use of irrigation treated waste water for crop production. Water productivity seed was calculated according to [24] as follows:

$$WP_{sunflower,\ canola,\ soybean}\ seed = Ey/Ir$$

where: WP sunflower is the water productivity of crop yield component (kg m^{-3} irrigation water), Ey is the economical yield (kg sunflower seed ha^{-1}) and Ir is the amount of applied irrigation water (m^{-3} irrigation water ha^{-1} $season^{-1}$).

Statistical Analysis: The data were subjected to statistical analysis of variance of Complete Randomized Block Design was carried out using MSTAT-C Computer Software [25]. Since the trend was similar in both seasons the homogeneity test Bartlet's equation was applied and the combined analysis of the two seasons was done. To differentiate between soil types T-test was employed.

RESULTS

Data in Table (2) present wastewater qualities applied to oil crops in both sites, all of these parameters are well within the maximum limit values set by the Egyptian Decree 44/2000 for wastewater reuse (Table 2). The amounts of wastewater irrigated to each crop and fertilizer treatment at both sites were recorded accurately Water requirements varied according to crop and season where the mean wastewater irrigation quantities recorded were 6034 m^3 ha^{-1}, 6792and 7638 m^3 ha^{-1} for soybean, canola and sunflower, respectively. The quantities of wastewater applied were broadly in line with normal farmer practice in the district. Calculating the major nutrients (NPK) supplied by wastewater as percentage of the fertilizer recommended rates indicated that treated wastewater TWW supplied N at 50, 40 and 35 % and P 61, 39 and 43% and K 223, 158 and 156 % of the recommended requirements of N, P and K for soybean, sunflower and canola, respectively in the clay soil while the corresponding values were 54, 61 and 79% for N, 88, 72 and 96 for P and 174, 99 and 191% for K in the sandy soil (El Berka site) for soybean, sunflower and canola, respectively (Table 3).

Highly significant increases in all of yield parameters of soybean characters were achieved by the treated wastewater TWW on yield characters (Table 4 amd Fig 1). Seed yield reached 5.38 t ha^{-1} and 1.475 t ha^{-1}, in clay and sandy soils, respectively. These yields were favourably higher than the national average yield of 2.64 t ha^{-1} in the clay soil, considering the lower quality of this soil. Straw yield also increased in clay soil but the seed, straw ratio was slightly smaller, indicating that optimum yield had not been reached. The oil content was significantly greater clay than sandy soil conditions and the increase under clay soil was more pronounced.

Data presented in Table (4) indicate that there were significant effects of soil type on all of the yield parameters of sunflower, with substantial increases in seed and straw yields The biodesel contents were 1.97 and 2.40 under sandy clay soil, respectively.

Data presented in Table (4) indicate that canola yields (seeds, straw and biological) were greater under clay soil compared with sandy soil. The oil production was of 5.01t ha^{-1} in clay soil compared with 0.548 t ha^{-1} in sandy soil.

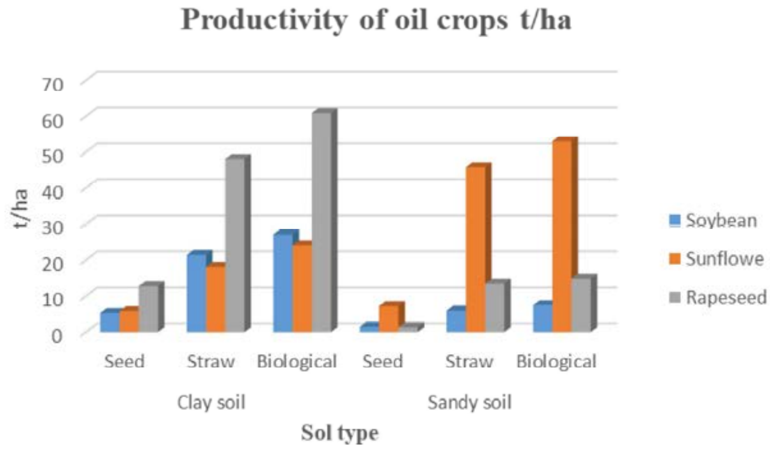

Fig 1: Yield components of oil crops (t ha^{-1}) irrigated with secondary treated wastewater TWW

Table 2: Chemical analyses of wastewater irrigated in the experimental sites.

		mg l^{-1}													
Parameters	pH	Tot. N	Tot. P	K	B	Fe	Mn	Cr	Ni	Zn	Cu	Cd	Pb	Co	Mo
Clay soil	7.83	9.7	2.6	19.0	0.34	0.362	0.113	0.021	0.025	0.162	0.043	<0.005	0.069	<0.01	0.01
Sandy soil	7.78	12.8	3.4	13.6	0.4	0.577	0.115	0.027	0.039	0.094	0.049	<0.005	0.079	<0.01	<0.005

Table 3: Proportion of nutrients supplied by wastewaters to oil crops compared with generally recommended rates of fertilizer

	Fertilizer recommended (kg/ha)			Addition in wastewater (kg/ha)			Nutrients supplied by wastewater as % of fertilizer		
Crop	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Clay soil (Clay soil)									
Soybean	108	54.0	57.6	54.2	33.1	128.2	50	61	223
Sunflower	108	74.4	57.6	43.4	26.6	102.7	40	36	178
Canola	108	54.0	57.6	38.2	23.3	90.0	35	43	156
Desert soil (Sandy soil)									
Soybean	144	54.0	57.6	77.5	47.3	100.3	54	88	174
Sunflower	144	74.4	115.2	88.1	53.8	114.0	61	72	99
Canola	108	54.0	57.6	85.0	51.8	109.9	79	96	191

Table 4: Yields components of oil crops (t ha^{-1}) irrigated with treated wastewater TWW

Soil type	Component	Soybean	Sunflower	Canola
Clay soil	Seed	5.38a	5.875b	12.785a
	Straw	21.43a	18.12b	48.065a
	Biological	26.995a	24b	60.855a
	Biodesel	1.06a	1.97b	5.01
Sandy soil	Seed	1.475b	7.225a	1.38b3a
	Straw	6.010b	45.775a	13.495b
	Biological	7.480b	53.005a	14.878b
	Biodesel	0.695b	2.420a	0.548b

Table 5: Water productivity kg m^{-3} in clay and sandy soil.

Soil type	Component	Soybean	Sunflower	Canola
Clay soil	Seed	0.88a	0.856a	1.6905a
	Straw	3.5475a	2.6445a	6.341a
	Biological	4.454a	3.501a	8.0315a
	Biodesel	0.1735a	0.287	0.663a
Sandy soil	Seed	0.226b	0.567b	1.065b
	Straw	0.919b	2.649b	6.742b
	Biological	1.143b	3.217b	7.807b
	Biodesel	0.107b	0.213b	0.357b

Water Productivity: Highly significant increases in all of water productivity of soybean yield components were achieved by in clay soil irrigated with the treated wastewater TWW. (Table 5 and Fig 2). Under sandy soil conditions water productivity was lower than the clay soil for WP_{seeds} and $WP_{biodesel}$ respectively achieving 0.226 and 0.695 kg m^{-3} for WP_{seeds} and $WP_{biodesel}$, respectively considering the poor quality of this soil. Straw water productivity also was similar for seeds and biodesel but the seed, straw water productivity ratio was slightly smaller, indicating that optimum water productivity had not been reached Fig 3.

Data presented in Table (5 and Fig 2) indicate that there were highly significant effects of soil type at all of the water productivity parameters of sunflower productivity for seed and biodesel compared with those achieved with sandy soil. This may be attributed in

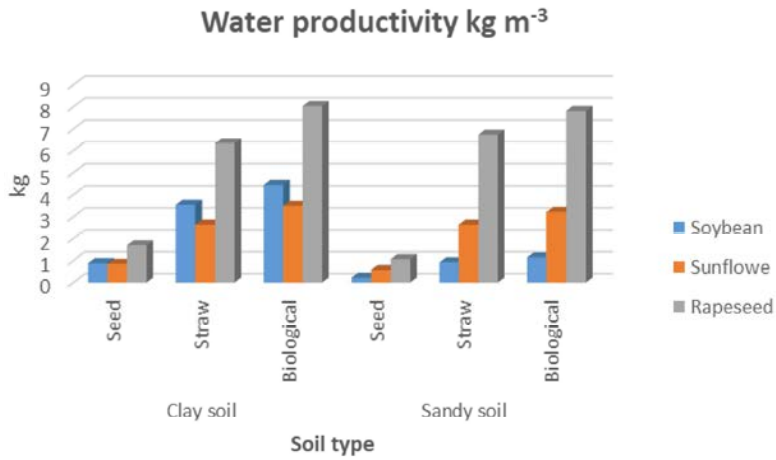

Fig. 2: Water productivity kg m^{-3} in clay and sandy soil.

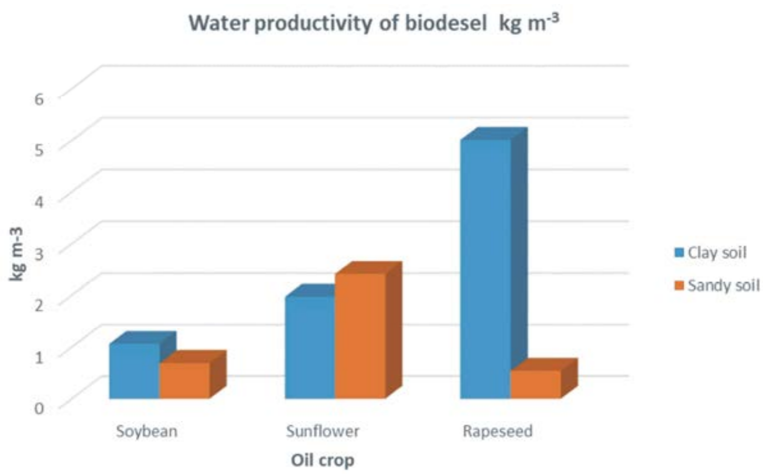

Fig. 3: Water productivity of biodesel production of different oil crops under two soil types

Table 6: Mean concentrations of heavy metals (ppm) in summer and winter crops at clay soil and sandy soil.

Crop	Soil type	Zn	Cu	Cr	Cd	Pb	Ni
Soybean	Clay soil	61.4	5.40	1.04	0.07	0.22	1.26
	Sandy soil	64.7	13.74	1.82	0.24	0.14	0.11
Sunflower	Clay soil	53.6	6.69	0.44	0.06	0.36	0.74
	Sandy soil	36.6	8.22	0.94	0.07	0.20	0.17
Canola	Clay soil	32.5	3.71	0.23	0.03	0.74	0.16
	Sandy soil	45.3	4.24	0.18	0.02	2.29	0.22

Note: Figures in bold for each element indicates the greater of pairs of mean concentrations for each crop.

part to the nutrient supply from Sandy soil wastewater which closely met with recommended amounts of fertilizer for this crop Fig 3.

Data presented in Table (5 and fig 2) indicate that canola water productivity of (seeds, straw and biological) significantly greater at clay soil. The biodesel content of canola seed $WP_{biodesel}$ at sandy soil was giving biodesel water production of 0.663 kg m^{-3} in clay soil compared with 0.357b kg m^{-3} at sandy soil Fig 3.

Effect of Irrigation Treated Wastewater of Oil Crops on Heavy Metal Content: The economic components of the crops grown during the field trials were analysed for heavy metal content. There were only a few occasions where there statistically significant differences in concentrations in crops irrigated by treated wastewater TWW. In general the trend was for smaller concentrations in the oil crops due to the dilution effect of greater growth with the additional nutrients of TWW. Crop off-take of heavy metals would be much greater from these treatments despite the smaller crop concentration. There were no consistent effects on crop quality resulting from the differing soil types. This is demonstrated by Table (7) where the mean concentrations of the principal heavy metals in the crops grown at Clay soil are compared with those from sandy soil and where the greater of the comparable pairs of concentrations occurred at similar frequencies between the two sites. Table (7) provides an even more condensed summary showing that there are only very small differences in overall crop quality between the sites.

DISCUSSION

The obtained results show that crop irrigation with wastewater provides a useful contribution to crop nutrient needs, these are applied uniformly throughout the growing period of the crop, whereas fertilizer (specifically nitrogen) is applied deliberately in targeted split applications according to the changing crop requirements during the growing cycle.

Irrigation with wastewater alone, particularly low fertility soils, results in poor early crop growth due to nutrient deficiency and normal levels of fertilizer should be applied during the early growth stages crops. Soybean seed and straw yields were approximately 50% greater at clay soil overall.

Sunflower yields were larger on sandy soil compared with clay soil. With treated wastewater TWW irrigation, seed yield at clay soil was similar to sandy soil. Consequently, the combination of sandy soil and wastewater would apparently suit sunflower growth more than at clay soil.

Chemical analysis of crops provides an indication of the quality of the crop in terms of its agronomic nutritional status and its dietary quality for human and animal consumption. Crop growth and quality is controlled principally by soil quality (physical and chemical) and nutrient supply, in addition to an adequate amount of water. The interactions between these factors are complex and this is illustrated by the comparison of the crop qualities from these trials conducted under contrasting soil conditions. As demonstrated above, treated wastewater TWW supplies only a proportion of the nitrogen and phosphorus requirements of the crop, but generally adequate levels of potassium. The crop yield responses showed conclusively that additional fertilizer is necessary to achieve reasonable crop growth response and economic yields. this is explained by the fact that crop growth and yields were increased by the addition of fertilizer compared with wastewater alone, often substantially depending on the crop and site and this in effect diluted tissue concentrations. These results demonstrate the importance of applying supplementary fertilizer at appropriate levels for the crop and soil and emphasize that the nutrients naturally present in wastewater which allow savings on fertilizer expenses to be realized [26, 27, 8, 13]. The advantage of field crop irrigation with treated wastewater TWW is evident from agronomic and economic scene. Several investigators assured that the nutrients naturally present in wastewater allow savings on fertilizer expenses to be realized [20, 8]. Also, Liu and Haynes [28] and Barreto *et al*., [8] indicated that depending on the nutrients, wastewater may be a potential source of macro- (N, P and K) and micronutrients (Ca, Mg, B, Mg, Fe, Mn or Zn).

The key conclusion from these data is that seed concentrations of nutrients and heavy metals are within the normally expected ranges for these crops. For all heavy metals (Table 6), seed concentrations were very small compared with toxic thresholds and consequently there are no environmental, health or crop quality implications. For some essential trace elements, particularly copper, concentrations were close to the deficiency thresholds at both sites.

The small concentrations of heavy metals in the seeds were expected and attributed to the high pH of the Egyptian soil which make the heavy metals are not readily bioavailable for crop uptake and do not represent a threat to the quality of the crops grown on this for human or animal consumption [30]. These results clearly reflect minimum pollution in the short and long terms and indicate the suitability of Cairo wastewater for reuse on the agricultural land. Similar results were obtained by Mahmoud *et al*. [30] in Jordan and WRc [29], Ministry of Water Resources and Irrigation [31] in Egypt. Canola is a relatively new crop in Egypt and so its yield characteristics are not yet fully evaluated under local conditions, but these results show clearly that canola is unsuited to inclay soil but can respond well to wastewater when grown on clay soil [27,13]. Finally, wastewater reuse has been proven to improve crop yield Jimenez [12] and Moscoso [13] and result in the reduced use of fertilizers in agriculture [14].

The use of biofuel as a sustainable substitute for petroleum diesel is a timely vital solution to the inescapable global issues related to environmental pollution and fossil fuel. Implementing biofuel is considered crucial for both economic and ecological reasons and has gained significant attention. Biodiesel is derived from lipids such as edible or non-edible oils reacting with alcohol with a catalyst [15]. Biodiesel, which is considered clean and environmentally friendly, could be produced from edible oils such as coconut, palm, olive and sunflower oil and non-edible oils such as rubber seed oil and algal oil using a process known as transesterification [16].

Several researchers have previously studied biodiesel production from fresh canola oil [17-19]. The major fatty acid of soybean oil is considered Linoleic acid based on the experimental analysis [20]. In short, biodiesel has attracted much attention due to its various environmental benefits. However, the main challenges include its production cost and availability of suitable raw materials. Edible oil source as a raw material for biodiesel production is not encouraging due to demand for food and the prices increase eventually.

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