ENERGY USE AND RELATED GREENHOUSE GAS EMISSIONS OF GROUNDWATER-IRRIGATED OIL SUNFLOWER PRODUCTION

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Abstract

In this study, oil sunflower production irrigated by groundwater was analysed in regards to the energy efficiency and greenhouse gas (GHG) emission. This research was performed at 19 farms growing sunflower under the irrigation area of Konya-Başgötüren town groundwater irrigation cooperative for 2019 vegetation cycle. The farmers applying drip and sprinkler irrigation systems were 6 and 13, respectively and they applied different irrigation levels. In that regard, by grouping farmers in accordance of irrigation methods and irrigation water regimes, separate treatments were obtained. In the context of the research, inputs used, amount of inputs as well as yield were determined individually in the farmer basis. By using unit energy equivalent of inputs and GHG emission factors energy input and GHG emission were determined and were assessed by using the relevant indicators. In results, sunflower production with drip irrigation system was found more successful in regard to the energy productivity. None difference was found between both the irrigation systems in term of the environmental impact. Drip irrigation with 250-350 mm water application was found the most successful in respect to the yield, energy productivity and low GHG emission.

Key words: oil sunflower, groundwater irrigation, energy efficiency, GHG emissions

Sunflower is among the most important oil crops worldwide and is originated from the Central America. Annual oil sunflower production of the world was 26533596 ha in 2017. Russia and Ukraine are the leading sunflower countries of the world. Among the first 10 countries with the greatest sunflower production lands, Turkey has the 7th place (FAOSTAT, 2019). Turkey is also among the important sunflower producer countries. In Turkey, oil sunflower was cultivated over 650870 ha land area in 2020 (TÜİK, 2021). However, only 26.1% of these production lands are used under irrigated conditions. In this sense, Konya province has an important share in sunflower production of Turkey (Yavuz N. *et al*, 2019). According to TÜİK data, in 2020, 10.3% of oil sunflower farming of Turkey was practiced in Konya province. Sunflower farming is generally practiced under irrigated conditions in Konya region and the province alone constitute about 43% of total irrigated sunflower farming lands of Turkey. In Konya region, irrigation is the most significant input in sunflower farming. Groundwater-based irrigation operations use quite much energy and thus constitute a significant cost item in agricultural practices. Groundwater resources are used in majority of irrigations performed in Konya region (Topak R. *et al*, 2008; Topak R. *et al*, 2011; Yavuz D. *et al*, 2015).

Agriculture production is both an energy user and energy supplier system. When using solar energy to produce biomass, plants capture atmospheric carbon dioxide (CO_2) as their main source of carbon. Agriculture supplies energy by growing crops that convert solar energy into biomass, which in turn supplies energy to human beings and animals. On the other hand, agriculture uses large quantities of energy inputs such as seed, diesel fuel, electricity, fertilizer, plant protection, chemicals, machinery and human labor. Besides the energy consumption, greenhouse gas (GHG) emission and global warming potential (GWP) issues are also critical in the agricultural production systems in recent twenty years (Khoshnevisan B. *et al*, 2013). Because, greenhouse gases such as carbon dioxide (CO_2) and non–CO_2 gases (N_2O: nitrous oxide; CH_4: methane) are produced as a result of agricultural activities, enhance the natural greenhouse effect. However, agricultural crops bind CO_2 from the air via the photosynthesis process, but crop production on farmer's field is also a source of GHG emissions. Moreover, for each crop the CO_2 fixation is much higher than the CO_2 emissions

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associated with the production of the crops (Küsters J., 2009).

As known, irrigation is an important energy user and the important a greenhouse gas emission item. Irrigation is needed huge amount of energy uses in Konya basin where particularly irrigation has performed by groundwater resources. The sunflower production under irrigation by groundwater supplies, therefore, was assessed by considering energy productivity and GHG emissions in this study.

MATERIALS AND METHODS

The subject and scope of the study

In the current study, oil sunflower production under irrigation by groundwater supplies was evaluated by considering energy efficacy and greenhouse, GHG, emissions. The research was performed under farmers' conditions at farms belonging Konya-Başgötüren province Groundwater Cooperative. In that regard, between farmers producing sunflower at Başgötüren Irrigation Cooperative 19 farms were selected randomly at 2019 production season. The 2019-year data relevant to the inputs (diesel fuel, electricity, human labor, machinery, fertilizer, irrigation system) and their amounts as well as crop yields of farmers were recorded individually. None suggestions were made for those farmers during the production period. The numbers of farmers applying drip and sprinkler irrigation techniques were 6 and 13, respectively. The rain-fed production of sunflower is not economical so such crop has growth under irrigation in our region. In this context, sunflower farming in such region was assessed in terms of the energy use efficiency and greenhouse (GHG) emissions. In that regard, irrigation practices performing by farmers was considered and research treatments were designated in accordance of irrigation technique and irrigation water levels. The treatments based on the farmer irrigation practices are presented at *table 1*.

Table 1

Oil sunflower production under different farmer irrigation treatments

Irrigation Methods	Irrigation Treatments	Amounts of Irrigation Water (mm)	Holding Numbers	Grain Yield (kg/ha)
Drip İrrigation (DI)	DI-1	230 (230 mm)	1	3680
	DI-2	355 (355 mm)	1	4000
	DI-3	452 (440-460 mm)	2	(3800-4000) 3900
	DI-4	500 (480-515 mm)	2	(3400-3600) 3500
Average				**3770**
Sprinkler İrrigation (SI)	SI-1	278 (248-299 mm)	4	(2200-3800) 3000
	SI-2	322 (300-345 mm)	3	(2800-3480) 3227
	SI-3	404 (385-415 mm)	4	(2200-3770) 3324,5
	SI-4	634 (630-640 mm)	2	(2400-2660) 2530
Average				**3020**

Energy analysis of oil sunflower production

An energy input-output analysis was performed to compare the efficiency of sunflower production under different irrigation methods and irrigation water amounts. This contex, per-hectare the all inputs and output values were converted to their energy equivalents by use of coefficients in *table 2.* The inputs used to produce the sunflower was analyzed including direct energy carriers (diesel fuel, electricity, human power), exploiting of fixed assets (tractor, machines, equipment, drip irrigation system) and consumption of materials (fertilizers).

Table 2

Energy coefficients of agricultural inputs and outputs in oil sunflower production

A-Inputs of production	Energy coefficient	References
Electricity	10.28 MJ/kWh	Acaroğlu M., 2001
Diesel fuel	40.68 MJ/L	Boustead I., 2003
Nitrogen	38.7 MJ/kg	Tzilivakis J. *et al,* 2005
P_2O_5	12 MJ/kg	Tzilivakis J. *et al,* 2005
K_2O	6.7 MJ/kg	Singh S., Mittal J.P., 1992
Machinery	49.35 MJ/kg	Hacıseferoğulları H., Acaroğlu M., 2015
Tractor	71.38 MJ/kg	Acaroğlu M., Aksoy A.Ş., 2005
Irrigation system		
Polyethylene (PE) embodied energy	75.2 MJ/kg	Ambrose M.D, *et al*, 2002
PE Ø125 mm tube	137,61 MJ/m	Calculated
PE Ø110 mm tube	106.78 MJ/m	Calculated
PE Ø90 mm tube	72.94 MJ/m	Calculated
PE Ø 22 mm tube (yassı)	1.5 MJ/m	Calculated
Human Labor	1.87 MJ/h	Fluck R.C., 1992
B-Output		
Seeds	26.2 MJ/kg	McIntosh C.S. *et al*, 1984

Total energy input was calculated by:
$EI_T=E\times E_1+D\times E_2+F\times E_3+M\times E_4+IS\times E_5+HP\times E_6$

Where:
EI_T – total energy input for groundwater irrigated sunflower productions (MJ/ha),
E – electricity consumption for irrigation (kWh/ha),
E_1 – energy coefficient for electricity (MJ/kWh),
D – diesel fuel consumption (L/ha),
E_2 – energy coefficient for diesel fuel (MJ/L),
F– amount of fertilizer applied (kg/ha),
E_3 – energy coefficient for fertilizer (MJ/kg),
M – input energy for machinery (h/ha),
E_4– energy coefficient for machinery (MJ/h),
IS – irrigation system for irrigation (m/ha),
E_5– energy coefficient for irrigation system (MJ/m),
HP – human power (h/ha),
E_6 – energy coefficient for human labor (MJ/h man).

Per-hectare the yield energy value of sunflower was calculated as below:

$YEV = YG\times E_C$

where:
YEV –yield energy value of sunflower (MJ/ha),
YG –grain yield (kg/ha),
E_C – the energy conversion coefficient for grains (MJ/kg).

There are indicators to assess energy efficiency of a production system. In this study, we used three parameters such as net energy yield (NEV), energy efficiency ratio (EER), energy productivity (EP) and energy irrigation water use efficiency (EWUE). NEY is the difference between the total energy produced and the total energy required to obtain it per hectare. EER was determined as energy output divided by energy input. EP describes how many kg of chickpea can be produced per one MJ of energy. EWUE is calculated as the ratio of energy output to total irrigation water applied.

Assessment of GHG emissions

To determine the impact of irrigation method and irrigation amounts on environmental pollution from sunflower production, an assessment of GHG emissions was performed. The total GHG emission for different treatments was obtained by calculating the emissions separately for input as diesel fuel, electricity, human power, agricultural machinery, fertilizers, and irrigation system. Taking into account the different units of measurement, the GHG emissions for the total production inputs were calculated in a unified CO_2eq system using the conversion equivalents in *table 3*.

Table 3

GHG emission factor values of agricultural inputs

Inputs of production	Emission factor	References
Electricity	0.55 kg CO_2 eq/kWh	Dulkadiroğlu H., 2018
Diesel fuel	2.76 kg CO_2 eq/L	Dyer J.A., Desjardins R.L., 2003
Human power	0.7 kg CO_2 eq/h	Nguyen T.L.T., Hermansen J.E., 2012
Nitrogen	7.759 kg CO_2 eq/kg	Chen S. *et al*, 2015
P_2O_5	2.332 kg CO_2 eq/kg	Chen S. *et al*, 2015
K_2O	0.660 kg CO_2 eq/kg	Chen S. *et al*, 2015
Machinery	0.071 kg CO_2 eq/MJ	Dyer J.A., Desjardins R.L., 2006
Polyethylene (PE) production	2.51 kg CO_2 eq/kg	Bai B. *et al*, 2006
PE Ø125 mm tube	4,59 kg CO_2eq/m	Calculated
PE Ø110 mm tube	3.56 kg CO_2 eq/m	Calculated
PE Ø90 mm tube	2,435 kg CO_2 eq/m	Calculated
PE Ø22 mm tube	0.05 kg CO_2 eq/m	Calculated
Output		
Yield (Dry matter)	0.45 kg C eq/kg	Epstein E., Bloom A., 2005; Bolinder M.A. *et al*, 2007; Sánchez-Sastre L.F. *et al*, 2018

The GHG emissions (kg CO_2eq/ ha) associated with the inputs to growing 1 ha of oil sunflower plants were computed as following.

$GHG_T=E\times F_1+D\times F_2+F\times F_3+M\times F_4+DS\times F_5+HP\times F_6$

Where:

GHG_T – total GHG emissions for irrigated sunflower production (kg CO_2 eq/ha),
E – electricity consumption for irrigation (kWh/ha),
F_1 – emission factor for electricity (kg CO_2eq/kWh),
D – diesel fuel consumption for field works (L/ha),
F_2 – emission factor for diesel fuel (kg CO_2eq/L),
F– amount of fertilizer applied (kg/ha),
F_3– emission factor for fertilizers (kg CO_2eq/kg),
M – input energy for machinery use (MJ/ha),
F_4– emission factor for machinery (kg CO_2eq/MJ),
DS – drip irrigation system for irrigation (m/ha),
F_5– emission factor for drip system (kg CO_2eq/m),
HP – human power for hoeing (h/ha),
F_6 – emission factor for human labor (kg CO_2eq/h man).

Due to the GHG emissions is based on carbon dioxide equivalent, to determine the carbon content this amount should be multiplied on ratio of carbon to carbon dioxide that it is 12/44. Moreover, for each irrigation application, carbon (C) yield of sunflower grains was determined. Per hectare the carbon yields of treatments were calculated as follows:

$$Y_C = GY \times C$$

Where:

Y_C – carbon amount of crop yield (kg/ha),

C – carbon content seeds (%).

In order to evaluate the results of GHG emissions, two functional indicators were chosen: specific GHG emissions (GHG_S) and areal GHG emissions (GHG_A). GHG_S is defined to evaluate the amount of emitted kg CO_2eq per kg yield. GHG_A is used to evaluate the amount of emitted kg CO_2eq per ha of farmland.

RESULTS AND DISCUSSION

Energy inputs and output

The total energy inputs of the sprinkler and drip irrigation methods were calculated by estimating the energy consumption related to electricity, diesel fuel, labor, machinery, fertilizers and irrigation system for each irrigation level. Results of input energy are given *table* 4 and 5. Although none difference was found between the irrigation methods in term of the total production energy, different irrigation water applications resulted difference in energy consumption (*table* 6).

Table 4

Inputs expressed as quantity per unit area for oil sunflower production

Treatments	Diesel Fuel (L/ha)	Electricity (kWh/ha)	Tractor (h/ha)	Plow (h/ha)	Cultivator (h/ha)	Sowing machine (h/ha)	Row crop cultivator (h/ha)	Combine harvester (h/ha)	N (kg/ha)	P_2O_5 (kg/ha)	Labor (h/ha)	PE1 (m/ha)	PE2 (m/ha)	PE3 (m/ha)	PE4 (m/ha)
DI-1	30.0	1168	4.90	2.0	1.00	1.2	0.7	1.33	128	72		250	150		7150
DI-2	44.1	2110	3.40	1.1	0.60	1.0	0.7	1.33	84	0		300	70		7150
DI-3	41.8	2410	4.10	1.5	0.90	1.05	0.65	1.33	91	50,5		200	225		7150
DI-4	35.6	2525	4.35	1.65	0.85	1.15	0.75	1.33	126	51		275	250		7150
SI-1	31.2	1473	4.37	1.43	1.05	1.13	0.78	1.33	127	62,3	60	225		480	
SI-2	29.5	1659	4.38	1.4	0.9	1.23	0.83	1.33	92	10	64	180		750	
SI-3	31.7	1890	4.43	1.25	0.95	1.25	0.98	1.33	68	20	55	105		700	
SI-4	31.2	3560	4.25	1.4	0.85	1.15	0.85	1.33	110	36	60	205		500	

PE= Polyethylen pipe; PE1= Ø 125 mm; PE2=Ø110 mm; PE3= Ø 90 mm; PE4= Ø22 mm

PE1, PE2 and PE3 = useful life 20 years; PE4= useful life 5 years

Table 5

Energy equivalents of agricultural inputs in oil sunflower production

Treatments	Diesel Fuel (MJ/ha)	Electricity (MJ/ha)	Tractor (MJ/ha)	Plow (MJ/ha)	Cultivator (MJ/ha)	Sowing machine (MJ/ha)	Row crop cultivator (MJ/ha)	Combine harvester (MJ/ha)	N (MJ/ha)	P_2O_5 (MJ/ha)	Labor (MJ/ha)	*PET (MJ/ha)	PE4 (MJ/ha)
DI-1	1220	12007	68.2	57.1	28.6	50.3	19	75.9	4953	864		2521	2145
DI-2	1794	21690	43.2	21.6	20	57.1	21.7	75.9	3250	0		2438	2145
DI-3	1702	24775	65.6	42.3	36.5	54.9	23.2	75.9	3521	606		2577	2145
DI-4	1450	25957	81.6	47.2	42	50.4	26.2	75.9	4876	612		3226	2145
SI-1	1268	15147	56.7	39.9	38.4	49.5	22.8	75.9	4903	747	132	3298	-
SI-2	1200	17054	71	31.1	39.2	52.8	25.9	75.9	3560	120	140	3974	--
SI-3	1292	19429	60.4	26.2	36.5	50.6	26.4	75.9	2632	240	121	3275	-
SI-4	1271	36596	69	39	33.4	57.7	23	75.9	4257	432	132	3234	-

***:** For drip irrigation PET= PE1+ PE2; For sprinkler irrigation PET = PE1 + PE3

The comparison of different irrigation levels in sunflower production showed that the highest total energy inputs (46220 MJ/ha) were in SI-4 treatment under the sprinkler irrigation. The lowest energy consumption (24009 MJ/ ha) was observed under the drip irrigation technique when 2300 m^3/ ha irrigation water (DS-1) was used. While the total energy consumption in drip irrigation ranged from 24009 (DI-1) to 38589 MJ/ ha (DI-4), sprinkler irrigation ranged between 25778 to 46220 MJ/ha. The researchers evaluated the energy inputs for sunflower production. For example, it was found this indicate was 10138-11045 MJ/ ha (McItosh C.S. *et al*, 1984; Kallivroussis L. *et al*, 2002; Unakıtan G., Aydın B., 2018) for rainfed-sunflower production and 15565 -18931 MJ/ ha for irrigated sunflower production system (Uzunöz M. *et al*. 2008; Baran M.F., Karaağaç H.A., 2014).

Compared with the DI-1, energy consumption was significantly higher under the others sprinkler and drip irrigation applications. The primary reason for the increase in total energy input was the increased electricity consumption for irrigation. As shown in Table 6, the highest amount of energy was consumed for irrigation (Electricity + irrigation system). The energy consumption of irrigation reached a value of 69.4% (DI-1) – 83.2% (DI-2) of total energy input in drip irrigation treatments and 71.6% (SI-1) – 86.2% (SI-4) of total energy input in sprinkler irrigations. The summarized energy consumption results show that the application of irrigation in sunflower production has a strong influence on the energy consumption. These results are consistent with those of other authors. Energy analyses of various agricultural operations done by previous researchers revealed that irrigation consumes significantly more energy compared to other agricultural operations, and the major share of energy consumed by irrigation operations comes from fossil energy, which is non-renewable (Batty J.C., Keller J., 1980; Mittal V.K., Dhawan K.C., 1989; Mrini M. *et al*, 2001; Topak R. *et al*, 2005, Topak R. *et al*, 2010; Yavuz D. *et al*, 2016).

The irrigation method and level of irrigation often affects crop yields. The crop yields of irrigation operations are presented in Table 6. The results of crop yield showed that drip irrigation has the higher average sunflower seed yield (3770 kg/ha) than sprinkler irrigation (3020 kg/ha). Of all the drip irrigations, the highest seed yield was obtained from DI-2 application (4000 kg/ ha), and the lowest seed yield (3500 kg/ ha) was under DI-4 conditions. On the other hand, grain yields ranged from 2530 kg/ ha to 3324.5 kg/ha in sprinkler irrigation applications.

From Table 6, it can be seen that the highest average output energy (OE) was obtained from drip irrigation (98774 MJ/ha). Compared to the output energy of drip irrigation group, the sprinkler irrigation group (79134 MJ/ ha) decreased the OE by 19.9%.

Energy balance indicators

For energy analysis, important energy indicators are the energy efficiency ratio (EER), net energy yield (NEY) and energy productivity (EP). The energy efficiency ratio shows how much energy was obtained and how much energy was used to grow sunflower per hectare. As seen in Table 6, the EER values of drip irrigation group are higher than that of sprinkler irrigation group. Moreover, drip irrigation was superior to sprinkler irrigation in terms of energy efficiency ratio. Although highest sunflower yield and energy output was observed under the DI-2 application, a slightly better energy efficiency ratio (4.02) was observed under the DI-1 application, whereas the worst ratio (1.43) was found under the SI-4 treatment.

Table 6

Energy assessment indicators of sunflower production

Treatments	Energy Consumption of Irrigation (Electricity+Irrigation system) (MJ/ha)	Total Energy Input (MJ/ ha)	Yield of grain (kg/ha)	Energy output (MJ/ ha)	EER	NEY (MJ/ ha)	EP (kg/MJ)	EIWUE (MJ/m^3)
DI-1	16673	24009	3680	96416	4.02	72407	0.15	41.9
DI-2	26273	31556	4000	104800	3.32	73244	0.13	29.5
DI-3	29497	35624	3900	102180	2.87	66556	0.11	22.6
DI-4	31329	38589	3500	91700	2.38	53111	0.09	18.3
Average	25932	32444	3770	98774	3.08	66330	0.12	28.08
SI-1	18445	25778	3000	78600	3.05	52822	0.12	28.3
SI-2	21028	26344	3227	84547	3.21	58230	0.12	26.3
SI-3	22704	27265	3324,5	87102	3.19	59837	0.12	21.5
SI-4	39830	46220	2530	66286	1.43	20066	0.05	10.5
Average	25501	31497,8	3020,4	79133,8	2.54	47635	0,10	21.65

The results of net energy yield (NEY) showed that the best average net energy yield (66330 MJ/ha) was under the drip irrigation, and in sprinkler irrigation, NEY was 47932 MJ/ha as group average. This result illustrates that drip irrigation was superior to sprinkler irrigation in terms of net energy gain in sunflower production. Drip irrigation applications, NEY values varied from 53111 MJ/ha (DI-4) to 73244 MJ/ha (DI-2). According to NEY values, there was no significant difference between the DI-1 (72407 MJ/ ha) and DI-2 (73244 MJ/ ha) applications. But compared to DI-2 application, DI-1 treatment saved 35.2 % from irrigation water and 44.6% from energy consumption for irrigation. Compared to DI-1 application, the DI-4 and DI-3 applications decreased the net energy yield by 26.6 % and 8.1%, respectively. Therefore, DI-1 application was recommended for sunflower production in the region studied.

Energy productivity (EP) is a very important indicator for evaluation the crop production systems and energy output. EP indicates sustainability and security in agricultural production systems. The results of this study showed that the consumption of 1.0 MJ of energy under drip irrigation can produce from 0.090 (DI-4) to 0.156 (DI-1) kilograms of sunflower seed. The EP values of sprinkler irrigation varied from 0.055 kg/ MJ (SI-4) to 0.12 kg/ MJ (SI-3). Sunflower plant produces no economic level a yield under non-irrigated conditions in Konya plain. However, in arid and semi-arid areas, energy input through irrigation is the most important energy input. Therefore, an energy irrigation water use efficiency (EIWUE) was computed and results were illustrated in Table 6. As shown in Table 6, the EIWUE values for applications varied from 10.4 MJ/ m^3 (SI-4) to 41.9 MJ/ m^3 (DI-1). The EIWUE values for drip irrigation applications were higher in comparison with sprinkler irrigation treatments. From these findings, it can be stated that the reduction of irrigation increased the EIWUE. Consequently, in terms of crop yield and energy, the best performance was achieved under the DI-1 and DI-2 applications by drip irrigation method. Moreover, DI-1 and DI-2 treatments were superior to others drip and sprinkler irrigation treatments in terms of energy performance.

GHG emissions assessment indicators

The GHG emissions based on different irrigation method and irrigation levels were computed and Table 7 is presented. The assessment of GHG emissions showed that reducing the irrigation levels had a positive effect on environmental pollution based on decreasing GHG emissions, although no significant difference was found between the sprinkler irrigation and drip irrigation methods. The GHG emissions were lowest as 2254 $kgCO_2eq$/ha when sunflowers were grown under drip irrigation method using 2300 $m^{3/}$ ha irrigation water. As seen from Table 7, no significant difference is found between the DI-1 and DI-2 applications. The highest GHG emissions (3343 $kgCO_2eq$/ ha) were under the sprinkler method, when irrigation operation was used 6300 m^3 / ha water. An analysis of the impact of individual irrigation operations on environmental pollution showed that the greatest proportion of GHG emissions was related to irrigation (Table 8). As can be seen from Table 8, GHG emissions based on irrigation ranged between 35.4 % (DI-1) to 58.2% (DI-2) under drip irrigation and between 40.4 % (SI-1) to 63% (SI-4) under sprinkler irrigation. This results show that the GHG emissions per unit of area increased as the irrigation water amounts increased. Some previous studies have reported that the main components of GHG emissions were electricity for irrigation. For example, it was found this indicate was 49.6–75.4% for irrigated winter wheat production (Wang Z. *et al*, 2016), 73% for irrigated sugar beet production (Yousefi M. *et al*, 2014), and also 63% for soybean production (Mohammadi A. *et al*, 2013).

Table 7

GHG emission values based on agricultural inputs used in oil sunflower production ($kgCO_2eq$/ha)

Treatments	Fuel Oil	Electricity	Machinery	N	P_2O_5	Labor	PET	PE4	Total
DI-1	82.8	642.4	212.4	993.2	167.9		84.1	71.6	2254.4
DI-2	121.7	1160.5	170	651.8	0		81.4	71.6	2257
DI-3	115.5	1325.5	211.9	706.1	117.8		85.9	71.6	2634.3
DI-4	98.4	1388.8	229.5	977.6	118.9		120.5	71.6	3005.3
SI-1	86.1	810.4	201.7	983.1	145.3	42	110		2378.6
SI-2	81.4	912.5	210	791.4	23.3	44.8	132.6		2196
SI-3	87.6	1039.5	196	527.6	46.6	38.5	109.3		2045.1
SI-4	86.3	1958	211.6	853.5	84	42	107.9		3343.3

Table 8

GHG emission assessment indicators of sunflower production

Treatments	Areal GHG Emissions				Specific GHG Emissions	Carbon output/ Carbon input
	Emitted GHG in Irrigation (Electricity+Irrigation system) (kg CO_2 eq/ ha)	Total GHG Emissions (kg CO_2 eq/ ha)	Input Carbon (kg C/ ha)	Output Carbon (kg C/ ha)	Yield (kg CO_2eq/kg)	
DI-1	798.1	2254.4	614.8	1656	0.61	2.69
DI-2	1313.5	2257	615.5	1800	0.56	2.92
DI-3	1483	2634.3	718.4	1755	0.67	2.44
DI-4	1580.9	3005.3	819.5	1575	0.86	1.92
Average	1293.9	2537.8	703	1696.5	0.65	2.4
SI-1	962.4	2378.6	648.6	1350	0.79	2.08
SI-2	1089.9	2196	598.9	1452	0.61	2.42
SI-3	1187.3	2045.1	557.7	1495.8	0.61	2.68
SI-4	2107.9	3343.3	911.7	1138.5	1.32	1.25
Average	1336.9	2490	679	1359	0.80	2.0

Although in terms of crop yield and energy the best performance was achieved under drip irrigation method, the environmental assessment revealed that only two drip irrigated -sunflower productions (DI-1 and DI-2) had lower environmental pollution compared with the other irrigation applications. Moreover, the DI-1 treatment decreased the seed yield and energy output by only 8.0%. On the other hand, DI-1 treatment saved by 35.2% of irrigation water, when compared to the DI-2 treatment.

Specific GHG (GHG_S) emissions of sunflower production under different irrigation method and irrigation levels are presented in Table 8. The GHG_S values were computed between 0.564 – 0.860 kg CO_2eq/ kg under drip irrigation (avg. 0.65 kg CO_2eq/ kg) and between 0.606 – 1.32 kg CO_2eq/kg under sprinkler method (avg. 0.80 kg CO_2eq/ kg). The highest GHG_S emission was achieved by SI-4 treatment (1.32 kg CO_2eq/kg), followed by DI-4 treatment (0.86 kg CO_2eq/ kg) and SI-1 treatment (0.79 kg CO_2eq/ kg), while the lowest GHG_S emission was found in DI-2 treatment (0.564 kg CO_2eq/kg).

As it can be seen in *table 8*, although in terms of carbon emission in sunflower farming no different between drip and sprinkler irrigation methods, drip method superior to sprinkler method in terms of accumulated carbon amount inside yield. Among drip irrigation applications, the DI-2 and DI-3 treatments returned the highest carbon outputs 1800 and 1755 kg C/ ha, respectively, and the sprinkler irrigation group, returning the lowest carbon outputs, which ranged from 1350 kg C/ha (SI-1) to 1495.8 kg C/ha (SI-3).

As can be seen from Table 8, carbon amount accumulated inside sunflower seeds is almost 2.4 in drip irrigation and 2 times in sprinkler irrigation more than the amount of carbon emitted in its production. These results have clearly shows that drip irrigated-sunflower production system was superior to the sprinkler irrigated-sunflower production in terms of carbon amount accumulated inside sunflower seeds.

CONCLUSIONS

The following conclusions can be drawn from this study:

1.In oil sunflower production, although none difference was found between sprinkler and drip irrigation systems in term of energy consumption, there was difference in terms of the energy production and energy efficacy. In that regard, drip irrigation was superior over sprinkler irrigation system.

2. None difference was found between irrigation methods in regard to GHG emissions, but there was found difference in respect to the carbon amount held by yield so drip irrigation was superior by comparison to sprinkler irrigation system.

3. Different applied irrigation water levels had effects on both the total energy consumption and production amount as well as total amount of GHG. The application of irrigation water by both the drip and sprinkler irrigation method over the certain amount had resulted no huge amount of yield increase, and increased both the energy uses and GHG emissions.

4. In summary of findings of the present study, 250-350 mm irrigation water application to the oil sunflower farms in region by drip irrigation method led to the maximum seed yield and net energy production, and minimum GHG emissions. As a result, irrigation program is a key area that can contribute to reducing environmental pollution in irrigated agricultural production.

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