Selcuk Journal of Agriculture and Food Sciences

http://sjafs.selcuk.edu.tr/sjafs/index

Research Article

SJAFS
(2020) 34 (3), 207-213
e-ISSN: 2458-8377
DOI:10.15316/SJAFS.2020.218

Environmental Mitigation Through Irrigation Management in Sugar Beet Production

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ARTICLE INFO

Article history:
Received date: 02.10.2020
Accepted date: 05.11.2020

Edited by:
Duran YAVUZ; *Selcuk University, Turkey*

Keywords:
Sugarbeet
Greenhouse gas (GHG) emissions
Irrigation
Environmental pollution

ABSTRACT

This study assesses the greenhouse gases (GHG) emissions of sugar beet production under different irrigation and nitrogen fertilizing strategies. This manuscript is an evaluation of the production inputs used in a research carried previous on sugar beet and its conversion into GHG emissions equivalent. This paper evaluates the potential for environmental mitigation, including the reduction of total GHG emissions from agricultural inputs in sugar beet production by managing irrigation and nitrogen fertilizing. In this context, the nine treatments based on three different irrigations (full irrigation, conventional deficit irrigation, partial root drying irrigation) and three nitrogen fertilization strategies (full nitrogen, partial deficit nitrogen, moderate deficit nitrogen) were assessed. The results of evaluation showed that DI-N_1 strategy can reduce irrigation water and nitrogen use up to 25% compared to control treatment (FI-N). In addition, this strategy saved 25% of electricity consumption use for irrigation. The analyse of pollution in this study led to very important findings: more environment-friendly irrigation and fertilization practices by using less water and nitrogen have a considerable potential for environmental mitigation in sugar beet production.

1. Introduction

Agriculture 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 diesel fuel, electricity, fertilizer, plant protection, chemicals, machinery and human labor. Besides the energy consumption, greenhouse gases (GHG) emission and global warming potential (GWP) issues are also critical in the agricultural production systems in recent twenty years (Khoshnevisan et al. 2013). Because, greenhouse gases 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 the GHG emissions. Also, for each crop the CO_2 fixation is much higher than the CO_2 emissions associated with the production of the crops (Küsters 1999).

Today the agriculture sector is one of main contributors for energy consumption and GHG emissions (Barker et al. 2009; Devi et al. 2009). Each year, agriculture emits 10–12% of the total estimated GHG emissions (Niggli et al. 2009). Studies of the direct energy use of on-farm operations suggest that grounwater pumping for irrigation is one of the highest energy consumption processes (Lal 2004; Mushtaq et al. 2009; Qiu et al. 2018). On a global scale, agricultural irrigation consumes approximately 70% of the world's fresh water supply; 90% of this irrigation takes place in arid and semi-arid areas (Viala 2008). Water resources are usually scarce in these areas and irrigation often requires electric energy to pump or divert water. Therefore, agricultural irrigation consumes both water and energy (Jimenez-Bello et al. 2015). Irrigation is important for achieving high yields in arid and semi-arid regions. Globally, 17% of irrigated cropland leads to 40% of the total production (Postel 1999). Yet, irrigation is a very carbon intensive practice. Irrigated agriculture around the world relies heavily on energy resources to extract freshwater and to convey it to application sites. This is especially the case in arid and semi-arid regions, where large amounts of irrigation water are required to sustain crop production. As a result, the availability and cost of energy are among major factors influencing the economic viability of irrigated agriculture in these regions. In addition, ener-

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gy consumption for irrigation has major environmental consequences, mainly due to the emission of GHG (Khan et al. 2014; Pradeleix et al. 2015; Handa et al. 2019).

Turkey produces about 18 million ton /year sugar beet root from 320 000 ha cultivation land area. Sugar beet is grown throughout Turkey under irrigated conditions. Konya basin produces about 42% of total sugar beet production in Turkey. Sugar beet is a major commercial field crop in this region which is the largest producer of Turkey (TÜİK 2020). The Konya basin, Middle Anatolian region in Turkey, lies within a semi-arid area with annual rainfall ranging from 280 to 500 mm (average 323 mm), and is one of the most important agricultural and agro-industrial regions. Water loss by evapotranspiration is very high during the growing season in the basin. However, available water resources of Konya basin are fairly scant. Thus, water is an essential component and the single most important factor in limiting crop production in the region (Topak et al. 2008). Irrigation water for crops is obtained mainly from ground water resources (Göçmez and İşçioğlu 2004) and there are approximately 100 000 deep wells in the basin (WWF 2014). This study is undertaken for making realistic assessment of GHG emissions from groundwater irrigated sugar beet production in Konya region in Turkey and evaluate the impact of irrigation management strategies for reducing the GHG emissions.

2. Materials and Methods

This study is used the data regarding the production inputs and yields of the field treatment of a project, which carried out on sugar beet by Topak et al (2014) in Konya conditions. In the article, we evaluated the effects of irrigation techniques and nitrogen doses on GHG emissions of sugar beet production, which is not within the scope of the project. In this context, the treatments are defined based on three different irrigation techniques and three nitrogen amounts as follows:

FI-N: Full irrigation + full nitrogen.

FI-N_1: Full irrigation + 75% of full nitrogen.

FI-N_2: Full irrigation + 50% of full nitrogen.

DI-N: 75% of full irrigation + full nitrogen. (DI: Conventional deficit irrigation)

DI-N_1: 75% of full irrigation + 75% of full nitrogen.

DI-N_2: 75% of full irrigation + 50% of full nitrogen.

PRD-N: 50% of full irrigation + full nitrogen. (PRD: Partial root drying irrigation)

PRD-N_1: 50% of full irrigation + 75% of full nitrogen.

PRD-N_2: 50% of full irrigation + 50% of full nitrogen.

In the mentioned project, irrigation water was taken from the deep well adjacent to the trial field with a flow rate of 75 m^3h^{-1}. The field experiment was irrigated by drip irrigation system. Irrigation was applied when 35–40% of the available soil moisture was consumed in the 0.90-m root zone in the FI treatment during the irrigation periods. The FI treatment was designated to receive 100% replenishment of soil water depletion. Depletion was defined as the difference between the depth of water held in the root zone at field capacity and the depth of water actually held in the root zone at the time of an irrigation decision. Fertilizers were applied on the basis of soil analysis. In soil samples, soil nitrogen before sowing was determined as 57.5 kg ha^{-1}. Diammonium phosphate fertilizer (18% N, 46% P_2O_5) was applied to the soil at a rate of 200 kg ha^{-1} prior to seeding. The remaining nitrogen amounts (N: 126.5; N1:85.9; N2: 45.3 $kgha^{-1}$) for the treatments were applied in the form of a urea fertilizer (46% N) in four equal parts during the first four irrigation cycles using a fertigation system. Total irrigation water, nitrogen amounts and root yields related to the treatments are given in Table 1. Production inputs and quantities related to the treatments examined are given in Table 2 and Table 3. Except for beet harvester, the input data were obtained from mentioned project records. Information associated with beet harvester was taken from farmers.

Since 1990, in Konya basin, over-exploitation from the groundwater resources is present. Long-term groundwater over-exploitation has led to a continuous decline in the groundwater depth in Konya basin and the groundwater table in the plains has decreased as well as notable. This decline of the groundwater table has led to an increase in energy consumption for groundwater exploitation. Therefore, electricity consumption per m^3 of groundwater has been revised according to today's conditions and taken into account as 0.5 kWh per m^3 water.

Table 1
Yield values with the amounts of nitrogen and water applied to treatments

Treatments	Nitrogen ($kg\ ha^{-1}$)	Irrigation Water (mm)	Crop water use (mm)	FRY ($kg\ ha^{-1}$)	SRY ($kg\ ha^{-1}$)	RDMY ($kg\ ha^{-1}$)	SY ($kg\ ha^{-1}$)
FI-N	162.5	851.1	961.8	93433	110951	21075	17803
FI-N_1	121.87	851.1	961.8	88715	107678	20450	17245
FI-N_2	81.25	851.1	961.8	88838	108660	20411	17405
DI -N	162.5	643.3	784.2	80818	101628	19344	16253

Table 1
Yield values with the amounts of nitrogen and water applied to treatments

DI-N_1	121.87	643.3	784.2	81653	105077	19915	16820
DI-N_2	81.25	643.3	784.2	79435	100187	18803	16028
PRD-N	162.5	435.6	588.5	66905	88733	16937	14210
PRD-N_1	121.87	435.6	588.5	65102	86870	16688	13913
PRD-N_2	81.25	435.6	588.5	66710	89266	16954	14295

FRY: Fresh root yield; RDMY: Root dry matter yield; SY: Sugar yield; SRY (Standardized Root Yield): root yield calculated according to the standard 16% sugar ratio.

Table 2
The inputs of sugarbeet production

Treatments	İnputs							
	Electricity ($kWh\ ha^{-1}$)	Diesel fuel ($L\ ha^{-1}$)	Nitrogen ($kg\ ha^{-1}$)	Phosphorus (P_2O_5) ($kg\ ha^{-1}$)	Potassium (K_2O) ($kg\ ha^{-1}$)	Human Labor ($h\ ha^{-1}$)	Drip system (Φ110 mm)* ($m\ ha^{-1}$)	Drip system (Φ 16 mm)** ($m\ ha^{-1}$)
FI-N	4255.5	105	162.5	92	70	240	120	22220
FI-N_1	4255.5	105	121.87	92	70	240	120	22220
FI-N_2	4255.5	105	81.25	92	70	240	120	22220
DI –N	3216.5	105	162.5	92	70	240	120	22220
DI-N_1	3216.5	105	121.87	92	70	240	120	22220
DI-N_2	3216.5	105	81.25	92	70	240	120	22220
PRD-N	2178	105	162.5	92	70	240	120	22220
PRD-N_1	2178	105	121.87	92	70	240	120	22220
PRD-N_2	2178	105	81.25	92	70	240	120	22220

*: Life 15 years; **: Life 7 years

Table 3
The energy input from agricultural machinery

Agricultural machinery	Machine Weight (kg)	Energy equivalent ($MJ\ kg^{-1}$)	Useful life (h)	Energy equivelent ($MJ\ h^{-1}$)	Working time ($h\ ha^{-1}$)	Machine energy ($MJ\ ha^{-1}$)
Beet harvester (6 rows)	24000	71.38*	12000	142.8	2	285.5
Tractor	3340	71.38*	16000***	14.9	8	117.7
Plow	350	49.35**	2000***	8.64	2.5	21.6
Cultivator	560	49.35**	2000***	13.8	1	9.87
Rotatil	700	49.35**	1500***	23.03	1.2	27.64
Fertilizer Spreader	100	49.35**	1200***	4.94	0.3	1.0
Sowing machine	530	49.35**	1500***	17.44	2	34.88
Row crop cultivator	430	49.35**	2000***	10.6	1	6.17
Total Machine Energy ($MJ\ ha^{1}$)						512.79

*Acaroğlu ve Aksoy (2005); ** Hacıseferoğulları ve Acaroğlu (2015); ***ASAE (1999).

The required energy in farm machinery manufacturing was calculated as:

$$E_M = (W_M / L_M) \times E \times T\ (MJ\ ha^{-1})$$

Where EM is the energy of the mobile and stationary mechanical power per unit area ($MJ\ ha^{-1}$); W_M is the weight of mechanical power (kg); L_M is the economic life of the mechanical power (h); E is the energy coefficient ($MJ\ kg^{-1}$); and T is the work hours per unit area per year ($h\ ha^{-1}$).

2.1. GHG emissions assessment

To determine the impact of irrigation level and nitrogen doses on environmental pollution from sugarbeet production, an assessment of GHG emissions was performed. The total GHG emissions for different treatments was obtained by calculating the emissions separately for input as fuel, electricity, human power, agricultural machinery, fertilizers, and drip 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 presented in Table 4.

Total GHG per hectare emissions is computed as:

$$GHG_T = E\times EF_1 + D\times EF_2 + F\times EF_3 + M\times EF_4 + DS\times EF_5 + HP \times EF_6$$

where:

GHG_T – total GHG emissions for irrigated sugarbeet production (kg CO_2 eq ha^{-1}),

E – electricity consumption for irrigation (kWh ha^{-1}),

EF_1– emission factor for electricity (kg CO_2 eq kWh^{-1}),

D – diesel fuel consumption for field works (L ha^{-1}),

EF_2 – emission factor for diesel fuel (kg CO_2 eq L^{-1}),

F– amount of fertilizer applied (kg ha^{-1}),

EF_3– emission factor for fertilizers (kg CO_2 eq kg^{-1}),

M – input energy for machinery use (MJ ha^{-1}),

EF_4– emission factor for machinery (kg CO_2 eq MJ^{-1}),

DS – drip irrigation system for irrigation (m ha^{-1}),

EF_5– emission factor for drip system (kg CO_2 eq m^{-1}),

HP – human power for hoeing (h ha^{-1}),

EF_6 – emission factor for human labor (kg CO_2 eq h^{-1}).

Table 4
GHG emission equivalent values of agricultural inputs

Inputs of production	Emission factor	References
Electricity	0.55 kg CO_2 eq kWh^{-1}	Dulkadiroğlu (2018)
Diesel fuel	2.76 kg CO_2 eq L^{-1}	Dyer and Desjardins (2003)
Human power	0.7 kg CO_2 eq h^{-1}	Nguyen and Hermansen (2012)
Nitrogen	7.759 kg CO_2 eq kg^{-1}	Chen et al. (2015)
P_2O_5	2.332 kg CO_2 eq kg^{-1}	Chen et al. (2015)
K_2O	0.660 kg CO_2 eq kg^{-1}	Chen et al. (2015)
Machinery	0.071 kg CO_2 eq MJ^{-1}	Dyer and Desjardins (2006)
Polyethylene (PE) production	2.51 kg CO_2 eq kg^{-1}	Bai et al (2006)
PE Φ110 mm tube	3.56 kg CO_2 eq m^{-1}	Calculated
PE Φ 16 mm tube	0.114 kg CO_2 eq m^{-1}	Calculated
Output		
Beet root (Dry matter)	0.45 kg C eq kg^{-1}	Epstein ve Bloom (2005) ;Bolinder et al(2007); Sánchez-Sastre et al (2018)

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 treatments, carbon (C) yield in root biomass was determined. The carbon yields of treatments per hectare is calculated as follows:

$Y_C = RDMY \times C$

where:

Y_C – carbon yield beet roots (kg ha^{-1}),

C – carbon content beet roots (%).

In order to show the results of GHG emissions, two functional units were chosen: 1 tone of product (root and sugar) and 1 ha of farmland. Therefore, specific GHG emissions (kg CO_2eq t^{-1}) and areal GHG emissions (kg CO_2eq ha^{-1}) were computed.

3. Results and Discussion

Table 5 displays the estimates of GHG emissions for different inputs used in sugarbeet production. They were calculated from the farming inputs detailed in Table 2 and Table 3 and by applying the emissions factors presented in Table 4. The GHG emissions of sugarbeet production varied under different irrigation techniques and nitrogen doses, and both root yield and GHG emissions decreased as the irrigation and nitrogen amount decreased (Table 6). Application of the deficit irrigation and reducing the nitrogen amount had a positive effect on environmental pollution based on decreasing GHG emissions. The comparison of different irrigation and nitrogen strategies in sugarbeet production showed that the highest GHG emissions (4746.6 kg CO_2eq ha^{-1}) was in the control treatment (FI-N). The lowest GHG emissions (2973 kg CO_2eq ha^{-1}) was observed under the PRD technique when %50 nitrogen deficit was used. Compared to control treatment (FI-N), the DI-N_1 treatment decreased the standardized root yield by only 5.0%. On the other hand, the GHG emissions per unit of area from DI-N_1 treatment was decreased by 18.7%, when compared to the FI-N treatment.

The results indicated that the main component of GHG emissions was electricity for irrigation. An analysis of the impact of sugarbeet cultivation on environmental pollution showed that the greatest proportion of GHG emissions was related to electricity for irrigation (from 33.2 % under PRD-N to 57% under FI-N_2) and nitrogen (from 15.3% under FI-N_2 to 42.4% under PRD-N). This results show that the GHG emissions per unit of area increased as the irrigation water and nitrogen 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 et el. 2016), 73% for irrigated sugar beet production (Yousefi et al. 2014), and also 63% for soybean production (Mohammadi et al. 2013).

GHG emission was achieved by the control (FI-N) treatment (42.8 kg CO_2eq t^{-1} SRY and 266.6 kg CO_2eq t^{-1} SY), followed by FI-N_1 treatment (41.2 kg CO_2eq t-

SRY and 257 kg CO_2eq t^{-1} SY) and DI-N treatment (41.1kg CO_2eq t^{-1} SRY and 256.8 kg CO_2eq t^{-1} SY), while the lowest GHG emission was found in PRD-N_2 treatment (33.3 kg CO_2eq t^{-1} SRY and 208 kg CO_2eq t^{-1} SY). As it can be seen in Table 6, the FI group required the highest total carbon inputs, which ranged from 1119.6 kg ha^{-1} (FI-N_2) to 1291 kg ha^{-1} (FI-N), whereas the PRD group required the lowest total carbon inputs, and the difference between the carbon inputs of these two groups were affected by deficit irrigation and nitrogen. Meanwhile, the FI-N, FI-N_1, and FI-N_2 treatments returned the highest carbon outputs 9483.8, 9202.5, and 9185 kg ha^{-1}, respectively, and the PRD group, returning the lowest carbon outputs, which ranged from 7509 kg ha^{-1} (PRD-N_1) to 7629 kg ha^{-1} (PRD-N_2). Compared to control treatment (FI-N), the DI-N_1 treatment decreased the SRY, SY and output carbon by only 5.0%. On the other hand, the GHG emissions per unit of area from DI-N_1 treatment was decreased by 18.7%, when compared to the FI-N treatment.

As can be seen from these results, carbon amount accumulated inside sugarbeet roots is almost 8 times more than the amount of carbon emitted in its production. In brief, sugarbeet is a plant with a high level of carbon fixation capacity.

Table 5
GHG emissions related to inputs of sugar beet production (kg CO_2 eq ha^{-1})

Treatments	İnputs of sugarbeet production								
	Electricity	Diesel fuel	Nitrogen	P_2O_5	K_2O	Agricultural machinery	Drip system (Φ110 mm)	Drip system (Φ 16 mm)	Human Power
FI-N	2340.5	289.8	1260.8	214.5	46.2	35.8	28.5	361.9	168
FI-N_1	2340.5	289.8	945.6	214.5	46.2	35.8	28.5	361.9	168
FI-N_2	2340.5	289.8	630.4	214.5	46.2	35.8	28.5	361.9	168
DI -N	1769	289.8	1260.8	214.5	46.2	35.8	28.5	361.9	168
DI-N_1	1769	289.8	945.6	214.5	46.2	35.8	28.5	361.9	168
DI-N_2	1769	289.8	630.4	214.5	46.2	35.8	28.5	361.9	168
PRD-N	1197.9	289.8	1260.8	214.5	46.2	35.8	28.5	361.9	168
PRD-N_1	1197.9	289.8	945.6	214.5	46.2	35.8	28.5	361.9	168
PRD-N_2	1197.9	289.8	630.4	214.5	46.2	35.8	28.5	361.9	168

Table 6
GHG emission indicators of sugar beet production

Treatments	Areal GHG emissions			Specific GHG emissions	
	Total GHG emissions (kg CO_2 eq ha^{-1})	Input Carbon (kg C ha^{-1})	Output Carbon (kg C ha^{-1})	SRY (kg CO_2eq t^{-1})	SY (kg CO_2eq t^{-1})
FI-N	4746.6	1291	9483.8	42.8	266.6
FI-N_1	4431.4	1205.3	9202.5	41.1	257
FI-N_2	4116.2	1119.6	9185	37.9	236.5
DI -N	4174.5	1135.5	8705	41.1	256.8
DI-N_1	3859.3	1049.7	8961.8	36.7	229.5
DI-N_2	3544.1	964	8461.4	35.4	221.1
PRD-N	3603.4	980.1	7621.7	40.6	253.6
PRD-N_1	3288.2	894.4	7509.6	37.9	236.3
PRD-N_2	2973	808.7	7629.3	33.3	208

SRY: Standardized root yield; SY: Raw sugar yield

4. Conclusions

This paper compares the potential for environmental mitigation, including the reduction of total GHG emissions from agricultural inputs in sugarbeet production by managing irrigation and nitrogen fertilizing. This article shows that sugar beet has a higher performance than many other plants in terms of fixed carbon amount. Although, the control treatment (FI-N) required the highest carbon inputs, produced the highest carbon output value. On the other hand, compared to FI-N, the DI-N_1 treatment decreased the output carbon by only 5.0 % and GHG emissions by 18.7 %. The results of this study indicated that although four treatments FI-N, FI-N_1, FI-N_2 and DI-N_1 showed the best SRY performance, the environmental assessment revealed that only one treatment (DI-N_1) had significantly lower environmental pollution compared with the other treatments (FI-N, FI-N_1 and FI-N_2). Moreover, DI-N_1 treatment saved 25% of irrigation water and nitrogen and 25% of electricity use in irrigation. Therefore, DI-N_1 treatment was recommended for sugarbeet production in the region studied.

5. Acknowledgment

This paper is derived the data regarding the production inputs and yield values of the field trial of a project (TÜBİTAK, project number:111O286), which carried out on sugar beet by Topak et al (2014) in Konya conditions.

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