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Full Length Research Paper

Sugar beet ecological emissions profile in East of Iran

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Iran is one of the main producers of sugar beet in the Middle East. Despite its great contribution to both local and global environmental impact, agricultural production systems in Iran is not very well investigated environmentally. This study characterizes some aspects of the environmental emissions inventory of sugar beet production in Iran, and compares the environmental performance of different cropping systems which include mechanized, semi-mechanized and traditional systems. Life cycle assessment methodology was used to classify and quantify the environmental emissions of sugar beet production. The life cycle inventory data reflect the cultivation profile of 93 sugar beet farms in 26 locations in Khorasan region in the east of Iran. Results of this study demonstrated that sugar beet produced in more mechanized cropping systems, can help reduce environmental emissions per functional unit. Comparing different cropping systems in each location evaluated in this study, only 19.7% of Khorasan sugar beet area performed well from the viewpoint of heavy metal emissions to water and soil, nitrate leaching and total emissions to air. The results suggest the maximum allowable levels of main environmental emissions for the discussion of improving the overall environmental profile of Iranian sugar beet, as well as these allowable levels in each cropping systems.

Key words: Sugar beet, agricultural products, life cycle assessment, environmental emissions, Iran.

INTRODUCTION

Until recently, agricultural production was optimised almost exclusively for profit but now farming is under pressure to meet environmental targets (Glending et al., 2009). Despite significant progress in agricultural knowledge and praxis, the agricultural sector faces enormous economic, social and environmental challenges. There is a growing awareness in many part of the world that agricultural production systems are neither sustainable nor healthy. Therefore, food production patterns needs to be based on a global, ecological view; minimal environmental impact and efficient utilization of resources must be made important criteria in the development of food products and the selection of food systems (Nemecek and Kagi, 2007; Andersson, 2000). Agriculture has a great role in Iran's economy. In 2007, agriculture accounted for 15% of the gross domestic product, 31% of non-oil exports, and 26% of the labor force (Khaledi and Rahimzadeh, 2008). Iran is one of the main producers of sugar beet (*Beta vulgaris L.*) in the Middle East. Both sugar beet production and sugar industries have a significant role in Iran's agriculture and agro-industries regarding technological, economical and social development of rural communities.

In 2007, sugar beet growing area was approximately 200,000 ha, and 5.3 million tons, 2.4% of the global total, were produced in Iran (Food and Agriculture Organization, 2010). North, Razavi and South Khorasan Provinces (the Khorasan region) in the east of Iran are the largest producers of sugar beet, and account for 35%

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of national production. Sugar beet production in the Khorasan region is irrigated, although there are some differences in the type of irrigation. Sugar beet farms also vary by the size of sugar beet production areas, which range from a few hectares to over one hundred hectares; cultivars, which include imported monogerm varieties and Iranian polygerm varieties, climatic differences, cultivation management, and the amounts of agricultural inputs. Khorasan sugar beet production systems can be divided into three types of cropping systems: 1) mechanized, 2) semi-mechanized and 3) traditional systems. In spite of great contribution to both local and global environmental impact and resource use (Davis et al., 2010); agricultural production is not very well investigated in Iran environmentally. Also, Iran currently has no official organic or environmental labels for agricultural products. However, a first version of a national guideline for organic production and labeling was released by the Iranian Institute of Standards and Industrial Research in January 2009 (Institute of Standard and Industrial Research of Iran, 2009). This guideline does not have official legal status.

Life cycle assessment (LCA) (International Organization Standardization 14040, 2006) is a technique for assessing the potential environmental impacts associated with a product, by compiling an inventory of relevant environmental exchanges of the product throughout its life cycle and evaluating the potential environmental impacts associated with those exchanges (Weidema and Meeusen, 2000). It considers all the aspects of resource use and environmental releases associated with a system, as defined by the function provided by a product, process, or activity. This cradle-to-grave approach considers all relevant impacts upstream and downstream of the consumer or producer (Curran, 2008). The first step in a LCA is to make an inventory of all relevant environmental interventions caused by the system under investigation. Environmental emissions inventory is one of the main parts of life cycle inventory (LCI). For agricultural LCAs usually the emissions of heavy metals, greenhouse gas emissions and nitrogen losses through leaching are important and need to be considered. The environmental emission profiles will be used to help the environmental protection programs assess which activities are most likely to cause environmental harm and rank them in order, from highest to lowest risk (Campin, 2008). This study aims thus to evaluate the environmental emissions profile of sugar beet produced in different cropping systems in Khorasan (east of Iran) using LCA methodology, and establishes the basis for sustainable sugar beet production.

METHODS

Goal and scope

LCA (International Organization Standardization 14040, 2006) was used to classify and quantify the environmental burdens and emissions of sugar beet production. Global warming potential, eutrophication potential, acidification potential, non-renewable energy demand, ozone depletion potential and land use were assessed as impact categories (Soltani et al., 2010). The goal of this paper was to present some aspects of the LCI of sugar beet production system in east of Iran, in order to obtain detailed production inventory data, identify drivers of sustainable beet production, and contribute to the development and application of LCA methodology in Iranian agriculture.

The scope of this work was to estimate environmental performance for sugar beet production, establishing parameters for sustainability and a future ecolabelling program for sugar beet in Iran. Three cropping systems are under investigation in this study are: 1) mechanized, 2) semi-mechanized and 3) traditional systems. Each cropping system in every location was determined by sugar beet experts of one of ten local sugar factories in the Khorasan region. The functional unit used in this study was 1000 kg of sugar beet.

System boundaries

The cradle to factory gate system is shown in Figure 1. The production of fertilizers, pesticides and agricultural machinery were not included in the system boundaries. Transport from farm to factory was estimated per farm, and transport to the farm of raw materials, fertilizers, soil correctors and pesticides was also taken into account. Field operations by farm equipments are also included in the system boundary, though their contribution to the overall impact may be negligible (Kim et al., 2009). Total energy accounts all upstream energy use to deliver electricity (from hydroelectric and fossil fuels plants) and diesel. Diesel consumption is due to the fuel burnt by the agricultural machinery, diesel irrigation pumps and in the transportation steps considered.

Data collection and quality

Most of the LCI data considered and evaluated in this study, such as planting, harvesting, field operations and their related fuel consumption, fertilizers, pesticides, road and field transportation and irrigation were gathered through in-depth questionnaires filled out directly in farm level by face to face interviews with the farmers and farm and factory managers. The data reflect the cultivation profile of 93 sugar beet farms grouped into three production systems, in 26 locations and 11 geographic regions in the east of Iran (North, Razavi and South Khorasan Provinces) (Table 1).

Emissions calculations

Quantifying environmental emissions associated with the agricultural field activities for the production of sugar beet in different cropping systems in the east of Iran, results of several surveys designed for farmers were completed with the literature and structured estimation methods. Heavy metal emissions to water and soil were assessed by a simple annual input (from fertilizer, pesticides, and seeds) output (from removed with biomass, leaching and erosion) balance by SALCA-heavy metal (Freiermuth, 2006; Nemecek and Erzinger, 2005). This can lead to negative emissions on the field level in some cases. Phosphorous based emissions due to the application of fertilizers were calculated according to Prasuhn (2006) and Audsley et al. (1997) cited in Nemecek and Kagi (2007).

The dynamics of available nitrogen in the soil, including the addition of fertiliser for each system/locations (SLs) were modelled using SUNDIAL (Smith et al., 1996) to estimate losses of nitrogen via leaching and denitrification. Ten sets of weather data for each

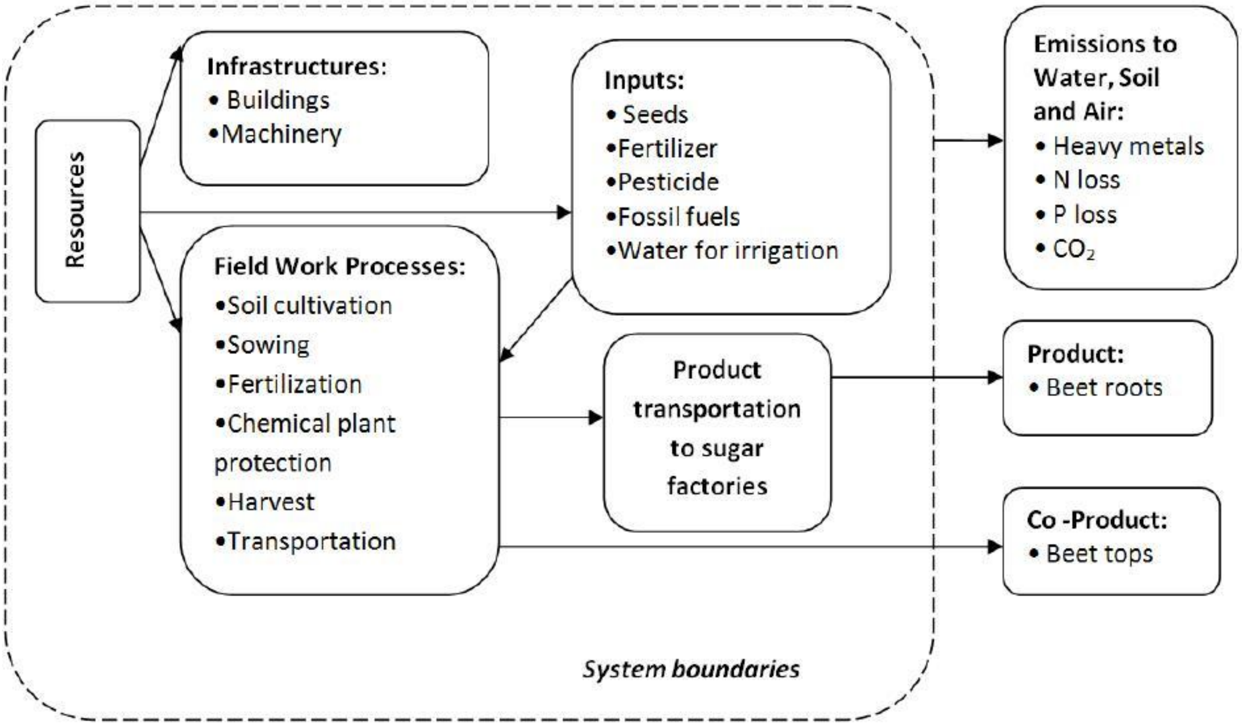

Figure 1. System boundaries considered in a life cycle inventories of sugar beet production system in the east of Iran.

geographical location were used (20 to 48 years average) to produce nitrogen losses for each of 26 Sls. Nitrous oxide (N_2O) emissions were estimated using an adapted IPCC method (Nemecek and Erzinger, 2005). Indirect emissions from the conversion of Ammonia (NH_3) and nitrate (NO_3^-) into N_2O were considered in the inventories as well. Nitrogen oxides (NO_X) emissions were estimated from the emissions of N_2O according to Nemecek and Kagi (2007) which includes the direct NO_X emissions from fertilizers and the soil only. The release of carbondioxide (CO_2) after urea application were calculated based on Nemecek and Kagi (2007).

RESULTS AND DISCUSSION

The main inputs of the LCI for sugar beet grown in Iran in three cropping systems for the functional unit of 1000 kg of sugar beet are shown in Table 2. The table presents the arithmetic average and the weighted average which indicate the productive contribution of each SL and area of each location respectively in related cropping system and also surplus index which shows the proportion of maximum value of each input in respect to arithmetic average (Coltro et al., 2006, 2009). The surplus indices shown in Table 2 indicate a large variation among the data, being the greater variation observed for the average values for traditional and semi-mechanized production system. This variation caused large differences in environmental emissions values in different sugar beet production systems as shown in Table 3. It shows that nitrate leaching in traditional system caused the greater surplus index indicating the maximum value of nitrate leaching in some locations ranges 4 times the average value. The results showed that sugar beet production in each cropping systems produced environmental emissions except for Zn and Cu for all systems and Pb and Ni just for mechanized system which their removed values from field were larger than their inputs. Mean Cd, Cu, Zn, Pb and Cr emission to water were 1.2, 84, 424, 1.3 and 522 mg for 1000 kg sugar beet production in Khorasan respectively (Figure 2). The results showed less lower emissions of heavy metals in more mechanized systems possibly due in part to high yield production that is, 60% of SLs with heavy metals emissions to water more than average were traditional while all of farms which produced mechanized sugar beet had heavy metal emissions lower than average to water.

The results of Nemecek and Kagi (2007) investigation clarified fewer emissions of Cd, Cu, Zn and Cr to water (0.48, 48, 364 and 261 respectively) for 1000 kg sugar beet in Switzerland whereas Pb emission to water (2.8 mg) was greater than the results of this study. Soltani et al. (2010) reported Cd, Cu, Zn, Pb and Cr emissions to water as 5.8, 393, 2220, 8 and 2472 mg for production of 1000 kg wheat in Gorgan in the North of Iran respectively. Nitrogen loss is becoming one of the major concerns as a pollutant in terrestrial ecosystems (Zhang et al., 2011). The mineral nitrogen in the soil is mainly nitrate and to a lower extent ammonium. The level of nitrate leaching depends strongly on different parameters which includes agriculture-related parameters like nitrogen balance, soil-related like field capacity in the

Table 1. Sugar beet production SLs evaluated in east of Iran.

SL	Geographic regions	Cropping system type[1]	% Area[2]	Location	/ Latitude Longitude	Altitude (m asl.)	Soil type	Rainfall index (mm/year)	Average air temperature (°C)	Average farm size (ha)	Cultivar
1	Mashad	M	5.48	Toos	36° 26 N/59° 33E	1020	Loam	248.6	15.3	14	Dorotea
2	Mashad	S	8.78	Nazer abad	36° 25 N/59° 29E	1029	Loamy sand	248.6	15.3	3	Orbis
3	Mashad	T	4.30	Qazqan	36° 14 N/59° 52E	906	Loamy clay	248.6	15.3	2	IC.
4	Chenaran	M	0.09	Hakim abad	36° 46 N/59° 53E	1180	Clay loam	210.5	13.4	50	Laetitia
5	Chenaran	S	3.40	Nowbahar	36° 35 N/59° 13E	1157	Loam	210.5	13.4	3	Laetitia
6	Ghoochan	M	N.A.	Almajeq	36° 53 N/58° 43E	1256	Loamy sand	311.1	12.9	90	Persia
7	Shirvan	M	3.06	Khoram abad	37° 20 N/58° 07E	1141	Loam	311.1	12.9	13	Castille
8	Shirvan	S	3.63	Devin	37° 18 N/58° 02E	1137	Loamy clay	311.1	12.9	5	Brigitta
9	Shirvan	T	2.08	Shoghan	37° 18 N/56° 48E	1222	Loamy clay	272.4	13.1	7	IC.
10	Neshabur	M	0.13	Hamid abad	36° 11 N/58° 55E	1305	Loamy sand	235	14.3	30	Dorotea
11	Neshabur	S	0.10	Hemat abad	36° 08 N/58° 39E	1108	Silt loam	235	14.3	15	PP22
12	Neshabur	T	0.19	Shoori	36° 17 N/58° 39E	1168	Loamy clay	235	14.3	1.2	IC.
13	Fariman	M	2.37	Fariman	35° 39 N/59° 50E	1455	Loamy sand	244.5	12.4	15	Paulina
14	Fariman	S	9.01	Karizan	35° 30 N/60° 12E	1187	Loam	244.5	12.4	1.75	Persia
15	Fariman	T	1.04	Loshab	35° 38 N/59° 48E	1495	Loamy sand	244.5	12.4	2	IC.
16	T. Heydariye	M	4.52	Kadkan	35° 39 N/58° 51E	1629	Loamy sand	258.5	14	9	Brigitta
17	T. Heydariye	S	13.66	Sonbole Rokh	35° 37 N/59° 16E	1663	Loam	227.9	11.16	2	Paulina
18	T. Heydariye	T	5.45	Zaveh	35° 16 N/59° 25E	1344	Loam	258.5	14	0.4	IC.
19	T. Jam	M	0.09	Bujgan	35° 09 N/60° 49E	809	Loam	176.4	15.7	200	Brigitta
20	T. Jam	S	2.52	Saleh abad	35° 49 N/60° 48E	971	Loam	176.4	15.7	7	Dorotea
21	Sabzevar	M	6.13	Jovein	36° 41 N/57° 15E	1113	Sandy loam	204.9	14.23	25	Paulina
22	Sabzevar	S	12.80	Hokm abad	36° 37 N/57° 33E	1098	Silt loam	204.9	14.23	1.75	Flores
23	Sabzevar	T	7.47	Soltan abad	36° 26 N/58° 02E	1169	Loamy silt	204.9	14.23	3	IC.
24	Sarakhs	S	N.A	Kandakly	36° 35 N/61° 03E	276	Loamy clay	190.6	18	1	IC.
25	Birjand	S	0.28	Sarbishe	32° 39 N/59° 46 E	1867	Loam	167.2	16.4	2	Fiamma
26	Birjand	T	2.95	Tabas e Masina	32° 57 N/59° 58 E	1538	Loamy clay	167.2	16.4	1	IC.

[1]M= Mechanized, S= semi-mechanized, T= traditional; [2]shows the proportion of Khorasan beet area estimated based on emerged area in each location –system on 2010 except for Jovein and Neshaboor on 2009. Data: Iranian Sugar Factories Syndicate.

effective rooting zone, and climate-related like drainage water rate (Brentrup et al., 2000). The weighted average of estimated nitrate leaching per ton of sugar beet produced in Khorasan was 0.52 Kg N (Table 3). Nitrate emission to water was also greater in traditional production system. While 89% of mechanized sugar beet producing farms had nitrate leaching lower than average, it was only 29% for traditional SLs (Figure 3). Similar

Table 2. Summary of environmental inputs inventories for 1000 kg of sugar beet production in different cropping systems in east of Iran.

Parameter	Unit	Traditional System			Semi-Mechanized System			Mechanized System			Total weighted average
		Weighted Average	Arithmetic Average	Surplus Index[1]	Weighted Average	Arithmetic Average	Surplus Index	Weighted Average	Arithmetic Average	Surplus Index	
Input											
Energy											
Total	MJ	9209	6788	3	5110	4916	2	2552	3896	1	5512
Electricity	MJ	5047	3416	3	4630	4355	2	2022	3440	2	4154
Diesel	MJ	4162	3372	11	480	561	1	530	456	1	1358
Water											
Irrigation water	m^3	490	496	2	319	406	3	170	223	1	326
Fertilizers											
Macronutrient	kg	12.3	11.4	2	10.4	10.1	2	6.5	6.9	1	10.0
Micronutrient	kg	0.3	0.2	3	0.3	0.3	2	0.2	0.2	1	0.3
Pesticide[2]											
Total	kg	0.119	0.108	1	0.111	0.146	3	0.096	0.084	1	0.110
Seed treat	kg	0.007	0.006	3	0.001	0.003	4	0.001	0.001	1	0.002
Fungicide	kg	0.025	0.025	3	0.013	0.027	3	0.010	0.022	3	0.015
Herbicide	kg	0.001	0.002	-	0.054	0.051	5	0.058	0.039	3	0.043
Insecticide	kg	0.086	0.075	3	0.042	0.066	3	0.027	0.022	1	0.049
Field Operation											
Total	ha	0.3	0.3	1	0.4	0.5	3	0.4	0.4	1	0.4
Transportation											
Total	km	74.4	62.3	4	38.6	64.3	4	27.4	28.6	1	44.6
Road trans.	km	74.2	62.1	4	38.2	63.8	4	26.6	28.0	1	44.1
Field trans.	km	0.2	0.3	1	0.4	0.6	3	0.8	0.5	3	0.4
Land use[3]											
Land use	ha.a	0.04	0.04	1	0.03	0.03	2	0.02	0.02	1	0.03

[1] Surplus index = Maximum value in related cropping system range divided by total arithmetic average; [2] on the basis of active substances; [3]LAND use = 1 ha.a for 1000 kg sugar beets production.

Table 3. Summary of environmental emissions inventory for 1000 kg of sugar beet production in different cropping systems in east of Iran.

Parameter	Unit	Traditional Systems			Semi-Mechanized Systems			Mechanized Systems			Total weighted average
		Weighted Average	Arithmetic Average	Surplus Index[1]	Weighted Average	Arithmetic Average	Surplus Index	Weighted Average	Arithmetic Average	Surplus Index	
Emissions to water											
Nitrate	kg	0.67	0.93	4	0.53	0.53	2	0.31	0.31	1	0.52
Cadmium	mg	2.05	2.01	2	1.05	1.27	3	0.67	0.69	1	1.20
Copper	mg	128.91	125.34	2	78.70	90.17	3	49.18	51.22	1	84.02
Zinc	mg	641.00	612.77	2	398.53	429.76	2	252.97	256.49	1	423.57
Lead	mg	1.76	1.64	2	1.33	1.30	2	0.89	0.88	1	1.33
Chromium	mg	868.80	849.87	2	462.33	556.65	3	300.71	307.38	1	522.47
Phosphate	kg	0.014	0.014	2	0.010	0.010	2	0.006	0.006	1	0.010
Emissions to soil											
Cadmium	mg	324.31	296.81	2	310.52	252.02	4	92.22	96.65	2	265.69
Copper	mg	-2723.9	-2719.7	1	-2558.0	-2569.1	1	-2872.7	-2812.2	1	-2666.3
Zinc	mg	-2193.4	-2241.9	1	-2436.4	-2364.9	-	-3881.9	-3590.9	1	-2697.5
Lead	mg	34.26	31.38	3	16.69	18.40	4	-2.04	0.41	1	16.71
Nickel	mg	178.42	157.14	3	166.32	125.47	7	-33	-21.02	2	125.27
Chromium	mg	814.9	696.82	2	1126.08	748.06	7	145.29	167.69	2	836.80
Emissions to air											
Ammonia	kg	0.67	0.47	3	0.57	0.64	3	0.35	0.37	1	0.54
Nitrous oxide	kg	0.1	0.1	2	0.08	0.08	2	0.06	0.06	1	0.08
Nitrogen oxides	kg	0.02	0.02	2	0.02	0.02	2	0.01	0.01	1	0.02
Carbon Dioxide	kg	9.21	8.93	2	7.67	7.60	2	4.75	5.15	1	7.39

[1]Surplus index = Maximum value in related cropping system range divided by total arithmetic average.

values were reported by Nemecek and Kagi (2007) for sugar beet in Switzerland (0.59 Kg N/ton) but Soltani et al. (2010) present higher values for wheat in Gorgan, Iran (32.4 Kg N/ton).

Results showed 0.54, 0.08, 0.02 and 7.39 Kg N Ammonia volatilization, N_2O, NO_x and CO_2 emissions for 1000 kg sugar beet production in Khorasan as weighted average respectively (Table 3). Ammonium contained in fertilizers can easily be converted into ammonia and released into the air. Ammonia contributes to acidification and eutrophication of sensitive ecosystems. Its impact can be mainly local and regional (Nemecek and Kagi, 2007). Similar to CO_2, N_2O and NO_x are greenhouse gases but with higher impact. During denitrification processes in soil, NO_x may be produced. N_2O was also emitted as a result of denitrification in anaerobic soil and nitrification in aerobic soils. Soil bulk density, large aggregates, nitrogen source and available carbon are the most important factors affecting soil NO_x emissions (Ussiri et al., 2009). Figure 4 shows total emissions to air produced by different production systems of sugar beet in Khorasan region. It includes Ammonia volatilization, N_2O, NO_x and CO_2 emissions. Traditional cropping system exhibited the highest emissions to air per

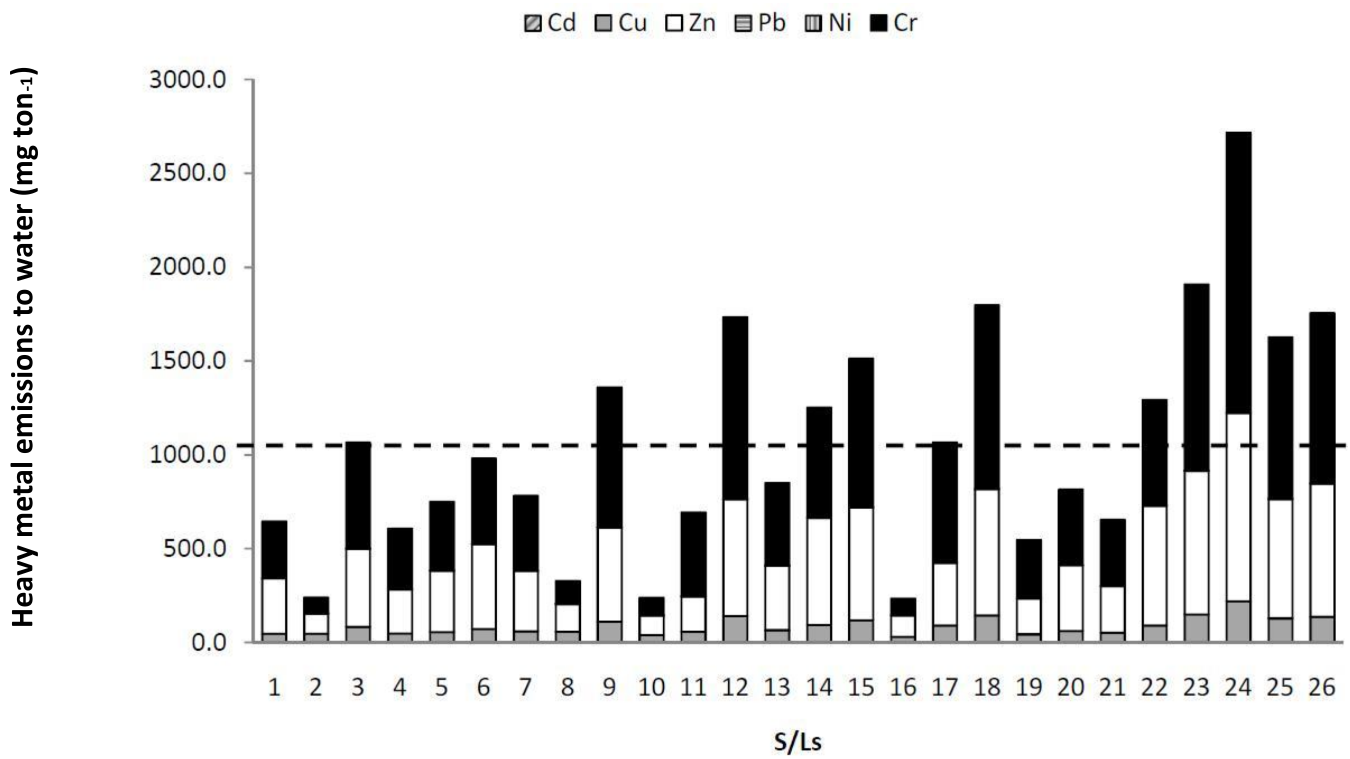

Figure 2. Heavy metal emissions to water in each SL evaluated in the life cycle inventory of sugar beet grown in east of Iran. Straight line represents the average.

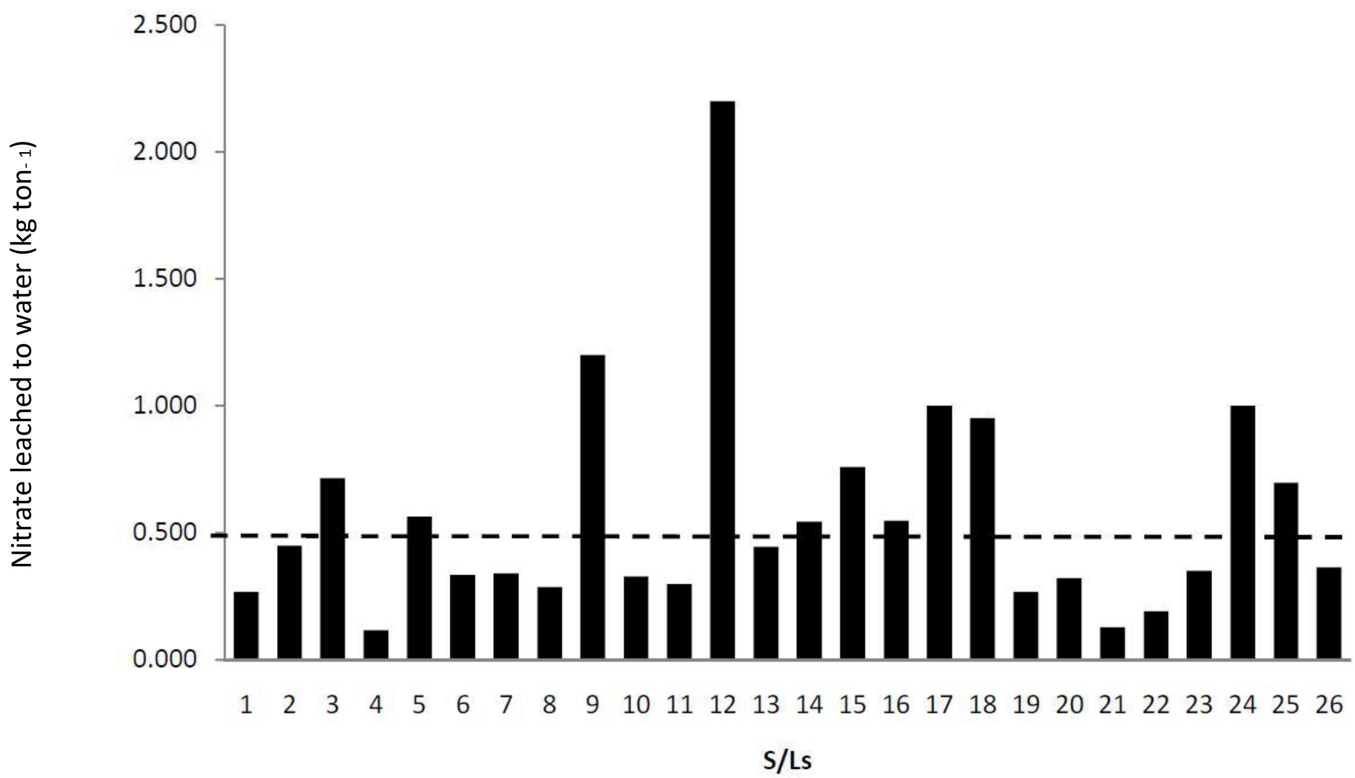

Figure 3. Nitrate leaching in each SL evaluated in the life cycle inventory of sugar beet grown in east of Iran. Straight line represents the average.

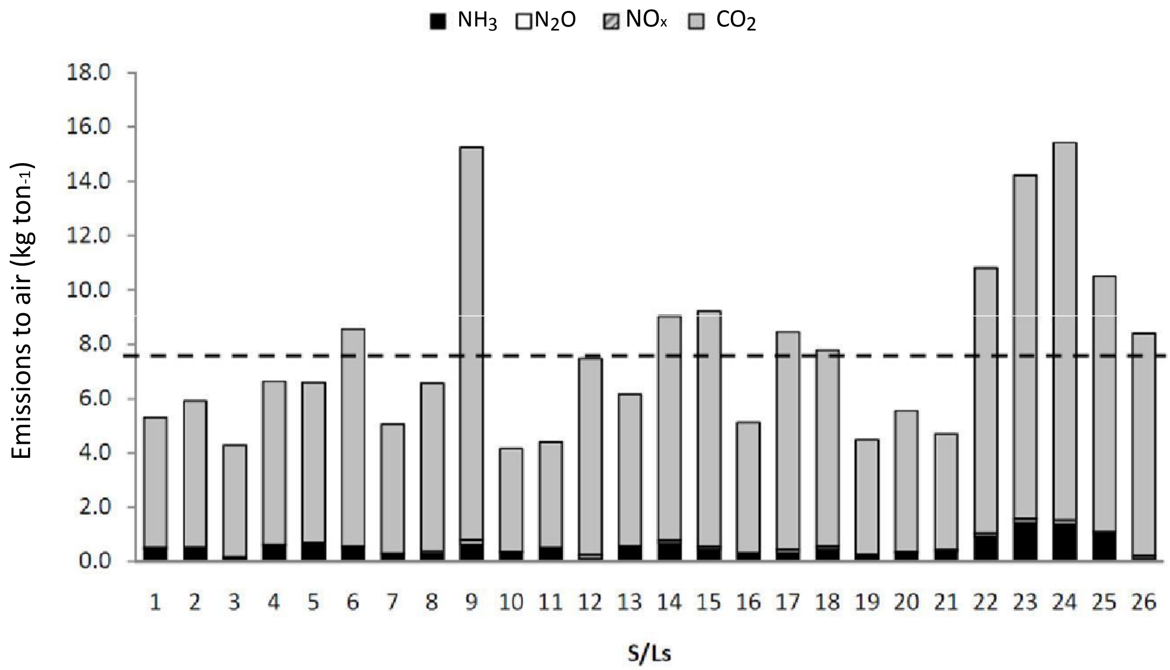

Figure 4. Environmental emissions to air in each SL evaluated in the life cycle inventory of sugar beet grown in east of Iran. Straight line represents the average.

1000 kg sugar beet production. The result indicated that more than 71% of tradition locations produced environmental emissions to air more than average while just one mechanized location (SL 6) had emissions to air higher than average.

In agreement with these results, Nemecek and Kagi (2007) reported 0.07 and 0.02 kg N/ton N_2O and NO_x emissions for sugar beet production in Switzerland but their estimation for ammonia volatilization and CO_2 emissions was 39 and 2.6% of results of the present study (0.21 and 0.19 kg N/ton). Ammonia volatilization, N_2O, NO_x and CO_2 emissions have been reported as 2.7, 0.76, 0.12 and 17.6 kg N/ton for wheat in Iran (Soltani et al., 2010). Analyzing heavy metal emissions to water and soil (Figure 5) or total environmental emissions to air (Figure 6) as a function of the productivity of each evaluated SL showed negative direct correlation of these emissions to the obtained yield of sugar beet in each SLs. It evidences a clear opportunity for reduction of environmental emissions and improve sugar beet production system in Iran in accordance with the environmental sustainability.

Conclusion

In order to evaluate the actual environmental emissions profile of sugar beet production, some of the main environmental emissions previously discussed and each SLs were compared with average emissions of the three different production systems. Seven SLs (1, 4, 7, 13, 19, 20 and 21) exhibited the best environmental emissions profile, when considering heavy metal emissions to water and soil, nitrate leaching and total emissions to air. Thus, taking into account the aspects evaluated in this study, only 19.71% of Khorasan sugar beet area performed well.

This work clearly demonstrated that in most of Khorasan sugar beet farms, especially in traditional cropping system, farmers applied excessive amount of inputs which led to excess of environmental emissions in comparison to average, and also showed a significant gap between Khorasan and Switzeralnd (as an optimum situation) that should be considered. The results of this study evidence possibility of reduction of environmental emissions to enhance both environmental and economical sustainability. These dual objectives can be achieved by a great revision not only in conventional farming systems but also by application of good agricultural practices and environmental management systems.

RECOMMENDATIONS AND PERSPECTIVES

Table 4 shows averages of environmental emissions of seven best performing SLs in Khorasan region. These emissions levels could be used as goals for future improvement in the overall environmental profile of Iranian sugar beet production. However, the best performing SL in mechanized, semi-mechanized and traditional production system (SLs 19, 20, 3, respectively)

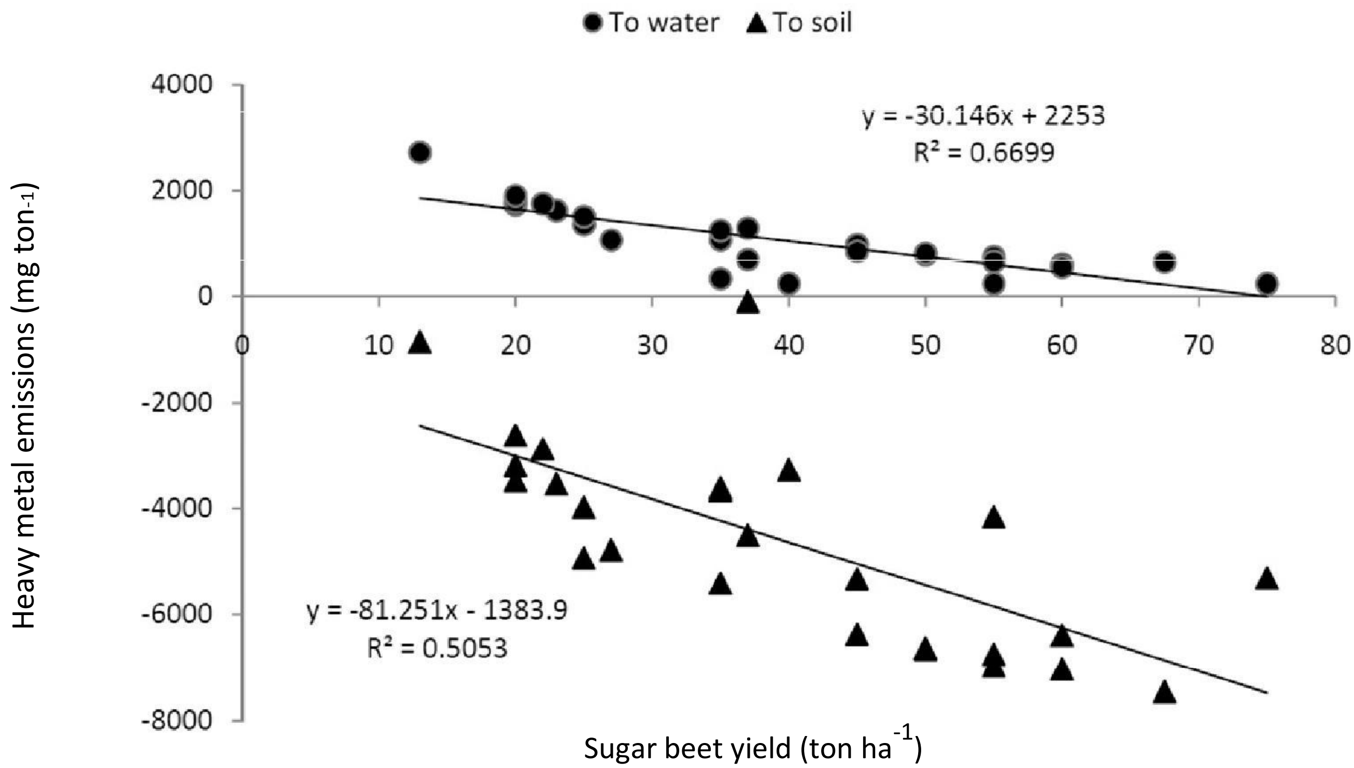

Figure 5. Heavy metal emissions in relation to sugar beet yields of each SL evaluated in the life cycle inventory of sugar beet grown in east of Iran.

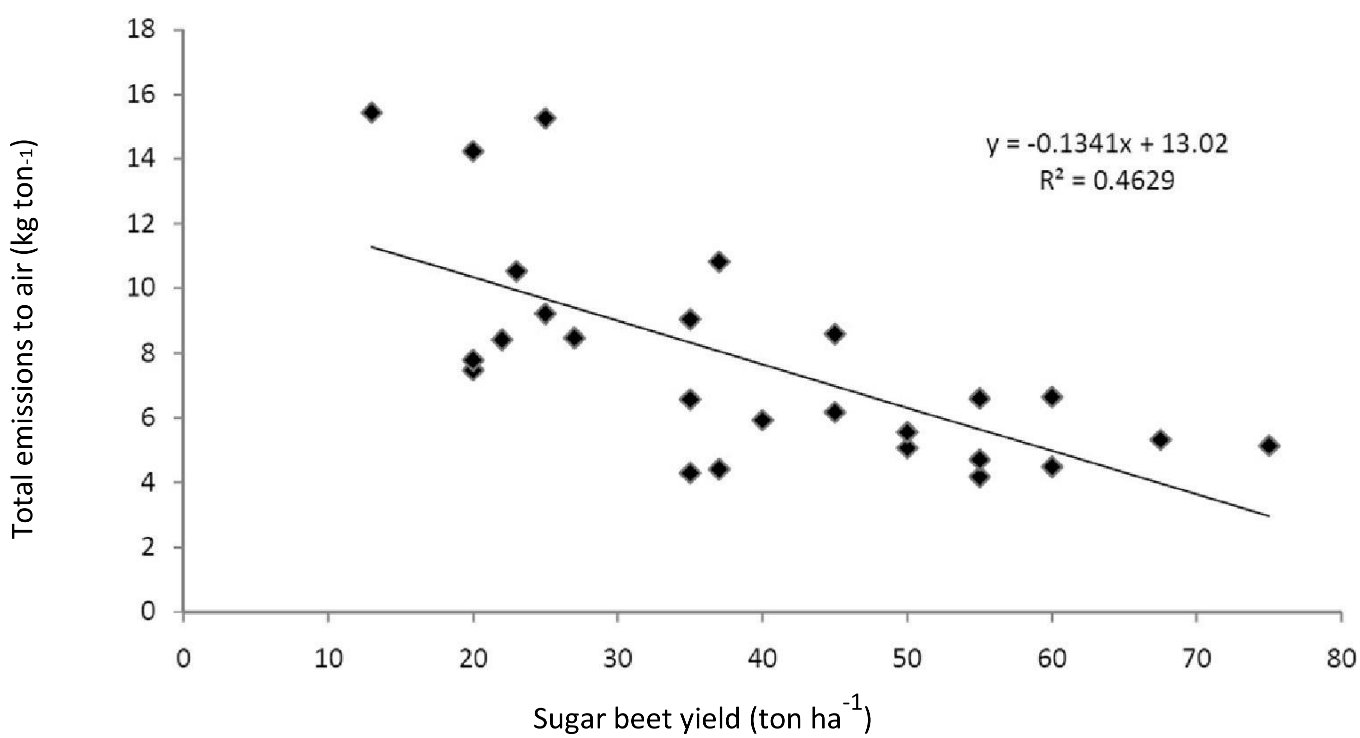

Figure 6. Total environmental emissions in relation to sugar beet yields of each SL evaluated in the life cycle inventory of sugar beet grown in east of Iran.

Table 4. Environmental emissions of best performance sugar beet production in different cropping systems and average of seven best performing SLs in east of Iran.

Parameter	Nitrate leaching ($kg\ t^{-1}$)	Heavy metals to air ($mg\ t^{-1}$)	Heavy metals to soil ($mg\ t^{-1}$)	Total emissions to air ($kg\ t^{-1}$)
Traditional	0.71	1066.7	-5408.5	4.29
Semi mechanized	0.32	816.0	-6659.4	5.56
Mechanized	0.27	546.6	-6298.8	4.48
7 Best-performing SLs	0.27	701.24	-6758.0	5.42

could be suggested as values of Table 4 to consider as the lower threshold to start up the aforementioned process of improvement.

Use of LCA is hindered by the lack of LCI data on agricultural inputs, processes and products (Pfefferli and Gaillard, 2000; Nemecek and Erzinger, 2005) in countries such as Iran. This study is the first attempt to develop a comprehensive life cycle inventory of sugar beet farming in the main producing region of Iran. In the next phase, this study will help the use of LCA for a complete environmental analysis of sugar beet production processes in Iran.

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