

The environmental impact assessment of wheat and barley production by using life cycle assessment (LCA) methodology

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Abstract This study was conducted to assess the impact of cereals (wheat and barley) production on environment under rainfed and irrigated farming systems in northeast of Iran. Life cycle assessment (LCA) was used as a methodology to assess all environmental impacts of cereal grain production through accounting and appraising the resource consumption and emissions. The functional unit considered in this study was one ton grain yield production under different rates of nitrogen application. All associated impacts of different range of N fertilizer application were evaluated on the basis of the functional unit. In this study, three major impact categories considered were climate change, acidification, and eutrophication. In order to prepare final evaluation of all impacts on environment, the EcoX was determined. Results represented that, under low consumption of N fertilizer, the environmental impacts of both rainfed farming systems of wheat and barley was less than irrigated farming systems. Considering grain yield as response factor to different fertilizer application level, irrigated farming systems of wheat and barley with the range of 160–180 and >220 (Kg N ha⁻¹) showed the maximum impact on environment. It seems LCA is an appropriate method to quantify the impact of utilized agricultural inputs and different managements on environment.

Keywords Acidification · Climate change · Eutrophication

1 Introduction

Semi-arid and arid lands constitute one-third of the global land area and are widely used for agricultural production (Harrison and Pearce 2000). Understanding environmental impacts of agricultural soils in these regions is necessary if we are to improve our knowledge of terrestrial global emissions. Among these regions, Iran has a favorable climate to produce variety of agricultural products. In arid and semi-arid regions of this country, the most conventional crops are wheat and barley, which are economically beneficial and are able to

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yield in arid environments. Total global cereal production is about 1.8 billion ton from which, 500–600 million ton is from wheat and 155 million ton is the contribution from barley. Total area under wheat cultivation in Iran is about 6.65 (Mha) in which 36.7 % of it is irrigated and the rest is managed under rainfed farming system. For barley, the total area of cultivated land in Iran is about 1.7 (Mha) in which 43.2 % of it is irrigated and 56.8 % is under rainfed system (Anonymous 2009). Among all provinces of Iran, Khorasan ranked first by allocating 9.21 % of the total area land to wheat cultivation. The total annual production of wheat in Iran is approximately 13.5 (Mton) in which 66.5 % of it is produced under irrigated systems and the rest is under the rainfed (Anonymous 2009). Although Khorasan province, compared to other crops, has the highest area under wheat cultivation and produce 8.4 % of total country wheat production, but it is in the third rank. Furthermore, in the case of barley, Khorasan not only has the highest cultivation land, about 13.6 % of total country, but in the first rank by producing 16.7 % of total country production (Anonymous 2009).

Considering the increasing global population, agriculture is responsible for food security. On the other hand, agricultural activities should be in a sustainable and environmental friendly manner. Nevertheless, synthetic chemicals and other environmental contaminants consumption, particularly in developing countries, have increased, resulting in different consequences such as soil acidification and salinization, emission of gases with adverse effects, nitrogen leaching to ground water, and eutrophication (Meisterling et al. 2009). However, the concern of scientists and policy makers has been evolved in an international manner (Anonymous 2008). Among all production sectors, agriculture has the closest interaction with nature (Bannayan et al. 2011a, b; Bannayan and Sanjani 2011). In regions of intensive agriculture, the contribution of farming systems to the degradation of the environment is increasingly investigated (Basset-Mens et al. 2006). Soil erosion and other environmental degradation impose an adverse impact on agriculture. Overuse of chemicals, synthetic fertilizers, pesticides, and other agricultural contaminants has brought irreversible antagonistic consequence for the nature (Karimzadegan et al. 2006). Since the late twentieth century, studies about input consumption in agriculture have initiated concerns and studies on environmental risk assessment. Many studies have been dedicated to find out the impact of these inputs particularly through global warming point of view and leaching of the N fertilizers, and based on such comprehensive information, 'Life Cycle Assessment' introduced to assess aggregated impacts on environment arising from farming systems (Payraudeau and Van der Werf 2005). The challenge of such tools is to be relevant both at a global scale, that is, for global impact categories such as climate change, and at a smaller scale, that is, for regional impact categories such as aquatic eutrophication (Basset-Mens et al. 2006). International Organization for Standardization (ISO) and Society for Environmental Toxicology and Chemistry (SETAC) (ISO 1997; Consoli et al. 1993) provided a general description of the LCA methodology. However, the impact assessment procedure, the aggregation methods for the different impact categories, and the final calculation of a summarizing environmental index are still in debate. Brentrup et al. (2004a) described one LCA method based on the general LCA methodology given by ISO (1997) and SETAC (Consoli et al. 1993) and adapted to the study of plant nutrition in crop production systems. Different ready-to-use LCA approaches, primarily designed for industrial applications, have been already published (Goedkoop 1995; Goedkoop and Spiensma 1999; Guinée et al. 2002; Heijungs 1992). It is, therefore, not surprising that there are problems concerning their application to arable crop production systems (Brentrup et al. 2001). Therefore, a new LCA approach was described by Brentrup et al. (2004a) to study the environmental impact of arable crop production. A major advantage of

this approach is the integration of all impact categories relevant to arable crop production. New impact assessment procedures, including aggregation, normalization, and weighting, have been developed for 'land use' and 'resource consumption' impact categories (Brentrup et al. 2002a, b). Life Cycle Assessment (LCA) is a methodology based on a global approach of the production system ('cradle-to-grave') and on a multicriteria approach of environmental impacts (Lehuger et al. 2009). An LCA compiles the inputs and outputs from a production system, and in turn evaluates their potential environmental impacts (Ekvall and Finnveden 2001), its principle consists of quantifying the resources consumed, and the emissions to the environment at all stages of the life cycle of the product (Guinée et al. 2002). All impacts are related to one common unit (e.g. 1 ton of wheat grain) and summarized into environmental effects (such as climate change or acidification) or even aggregated into a summarizing environmental index. Such an index allows the ranking of different product or production alternatives according to their overall environmental performance (Brentrup et al. 2004a). The impacts were calculated by aggregating the life cycle impacts of the various ingredients of the rations (Lehuger et al. 2009).

Due to increasing utilization of synthetic chemical inputs in agriculture business in Iran and its consequent environmental impacts, LCA seems to be an appropriate method to quantify such impacts and decrease adverse effects as much as possible. The objective of this study was to estimate the impacts of rainfed and irrigated wheat and barley production at different N application on environment in the Khorasan provinces of Iran.

2 Materials and methods

This study was conducted to assess the impact of cereals (wheat and barley) production on environment under rainfed and irrigated farming systems in northeast of Iran (Fig. 1). In order to assess the relevant environmental impacts due to a specific process, using LCA

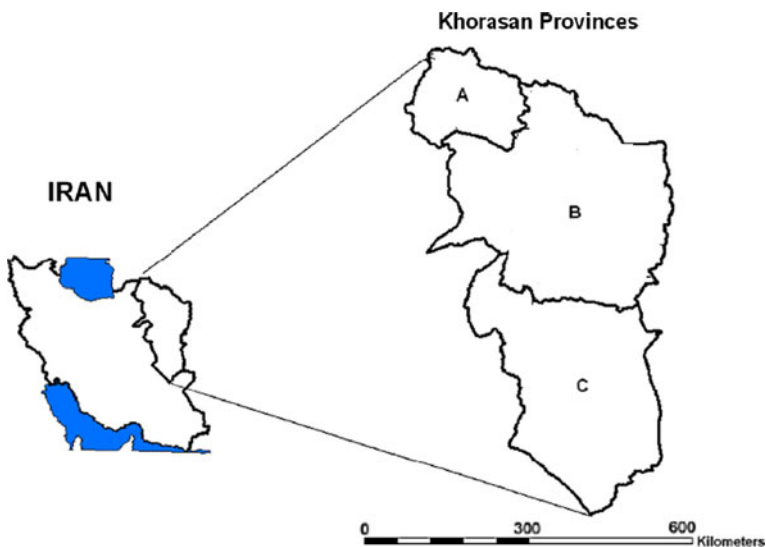


Fig. 1 Geographical study location (A Khorasan Shomali, B Khorasan Razavi, C Khorasan Jonoubi)

method, two factors concerned to resource consumption and contaminants emissions were calculated. This was based on this fact that LCA is a target process to investigate the environmental capacity of production, energy used in different process, resource consumption, and residuals in environment (Roy et al. 2009). This study was carried out using LCA methodology in compliance with ISO14044 (ISO 1997; Brenttrup et al. 2004a). In this regard, four phases, which are goal and scope definition, inventory analysis, impact assessment, and interpretation, were designed to assess life cycle index (Figs. 1, 2).

The system investigated in this study is an arable farming system with main function to produce wheat and barley. In the subsequent life cycle inventory (LCI), the resource consumption (inputs) and emissions (outputs) connected to the system are compiled. To make the various inputs and outputs comparable, it is necessary to relate these data to a common functional unit, which shall represent the main function of the system (Brenttrup et al. 2004a). Therefore, this study relates all resource consumption and emissions to 1 ton of grain. Then, all resources and emissions per each ton of wheat and barley grain were quantified. In the third step, a life cycle impact assessment (LCIA) must be made in order to evaluate the inventory data. Within the LCIA, the different inputs and outputs are summarized into environmental effects (Brenttrup et al. 2004a). Based on ISO instruction, the impacts included contaminants emission to atmosphere, soil, and water (Finkbeiner et al. 2006). In this study, three main categories as impacts on environment including climate change (as global warming), acidification, and eutrophication (terrestrial and aquatic) were defined, and the impact of wheat and barley production was determined under these categories. Emissions of gases with specific radiative characteristics like carbon dioxide (CO₂) and nitrous oxide (N₂O) lead to an unnatural warming of the earth's surface, which in turn will cause global and regional climatic changes. This environmental impact is commonly described as 'global warming'. The term 'climate change' indicates that the possible consequences of global warming concern more elements of the global climate than only the temperature (Brenttrup et al. 2004a).

The first step in LCIA is the characterization step. During characterization, the inventory data are aggregated into indicators for each impact category (Table 1). Characterization is achieved through the use of characterization factors, which represent the potential of each emission to contribute to a specific environmental effect. For instance, the main greenhouse gases have been studied in agriculture are CO₂, CH₄, and NO_x, which can be expressed in CO₂ equivalents (ISO 2006). Acidification index was estimated based on the amount of minerals leached into the soil. The process of acidification usually occurs

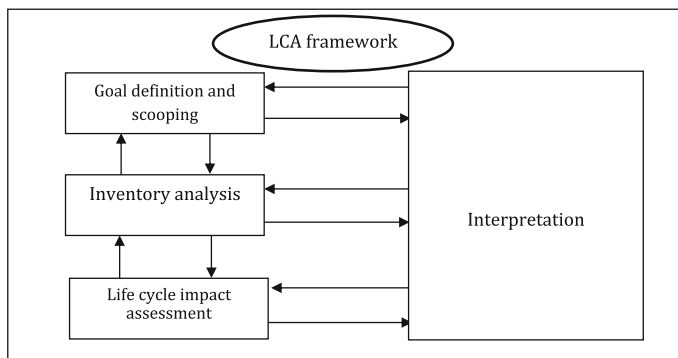


Fig. 2 Life cycle assessment framework

Table 1 Characterization factors for each impact category

Substance (in kg)	Global warming potential (in kg CO ₂ equivalents per kg)
<i>Global warming^a</i>	
CO ₂	1
CH ₄	21
N ₂ O	310
Substance (in kg)	Acidification potential (in kg SO ₂ equivalents per kg emission)
<i>Acidification</i>	
SO ₂	1
NO _x	0.28
NH ₃	1.30
Substance (in kg)	Terrestrial eutrophication potential (in kg NO _x equivalents per kg emission)
<i>Terrestrial eutrophication</i>	
NO _x	1
NH ₃	5
Substance (in kg)	Aquatic eutrophication potential (in kg PO ₄ equivalents per kg emission)
<i>Aquatic eutrophication</i>	
P	1
NO ₃	0.1
NO _x	0.13
NH ₃	0.35
N	0.42
NO ₃ -N	0.42

^a Brentrup et al. (2004a), Biswas et al. (2008)

due to NH₃, NO_x, and SO₂ emission. As the acidification potential of these gases is different, it is usually expressed in SO₂ equivalence. In this study, in order to calculate eutrophication index, the method introduced by Brentrup et al. (2004a, b) has been used. The coefficients of impact categories are presented in Table 1. The inventory data are multiplied by characterization factors (CF) to give indicators for the so-called environmental impact categories (Eq. 1).

$$IC_i = \sum (E_j) \times CF_{ij} \quad (1)$$

where IC_{*i*} (impact category indicator) is indicator value per functional unit for impact category *i*; E_{*j*} is release of emission *j* or consumption of resource *j* per functional unit; CF_{*ij*} is characterization factor for emission *j* or resource *j* contributing to impact category *i* (Meisterling et al. 2009).

To compare the indicators, they were normalized. During the normalization, the indicator results per functional unit were related to the respective indicator results for defined reference area according to Eq. (2).

$$N_i = \frac{I_i}{NV_i} \quad (2)$$

where N_i is normalization result per functional unit for impact category i ; I_i is indicator value per functional unit for impact category i ; NV_i is indicator value for a reference situation (e.g. per person in Europe) for impact category i (Meisterling et al. 2009).

Weighting normalized indices were also required and calculated as Eq. (3). Weighting step aims at a final aggregation across all impact categories to one overall environmental indicator. Therefore, each normalized indicator value is multiplied by a weighting factor (Brentrup et al. 2004a).

$$WF_i = \frac{C_i}{T_i} \quad (3)$$

where WF_i is weighting factor for impact category i , C_i is current indicator value for impact category i , and T_i is target indicator value for impact category i .

Finally, an index so-called environmental index (EcoX) was calculated as Eq. (4):

$$\text{EcoX} = \sum N_i \times WF_i \quad (4)$$

where EcoX is the environmental index per functional unit, N_i is normalized result per functional unit for impact category i , and WF_i is weighted factor for impact category i . Higher EcoX translates as higher burden on environment due to target production.

Data used in this study including the amount of consumed chemical fertilizers, machine operation, and fossil fuel consumption for wheat and barley production in Khorasan provinces during 1999–2009 were collected from data bank of Iran Agricultural Ministry (Anonymous 2009).

3 Results and discussion

Field data showed that the harvested yields were different based on the rate of consumed N fertilizer (Table 2). The highest and the lowest rainfed yields were 0.8 and 0.2 (t/ha) and irrigated yields were 6.27 and 2.0 (t/ha). Irregular precipitation resulted in high variability of rainfed cereal production, as in some years, most of rainfed land had low yield to harvest (Bannayan et al. 2010). Similar to wheat, the yield of rainfed barely was considerably low due to low precipitation at the rate of 10–20 kg N fertilizer per hectare.

Table 2 The yield of wheat and barley at different rate of fertilizer

Irrigated barley		Rainfed barley		Irrigated wheat		Rainfed wheat	
Yield (t/ha)	Rate of fertilizer application (kg)	Yield (t/ha)	Rate of fertilizer application (kg)	Yield (t/ha)	Rate of fertilizer application (kg)	Yield (t/ha)	Rate of fertilizer application (kg)
1.96	140–160	0.56	0–10	2.01	160–180	0.25	0–10
2.85	160–180	0.36	10–20	5.15	180–200	0.60	10–20
3.04	180–200	0.55	20–30	6.27	200–220	0.41	20–30
3.49	200–220	0.88	30–40	4.15	220–240	0.84	30–40
3.13	220<	0.96	40–50	4.61	240<	0.57	40<

Table 3 Emissions (kg) per ton of grain for the different N fertilizer rates

N Fertilizer rates (kg/ha)	NH ₃	NH ₄	NO _x	NO ₃	P	NO ₃ -N	SO ₂	CO ₂	CH ₄	N ₂ O
<i>Irrigated barley</i>										
140–160	3.543	0.386	1.055	0.117	0.532	0.491	0.637	428.414	20.914	420.236
160–180	2.876	0.313	0.856	0.095	0.407	0.398	0.517	408.875	16.977	417.678
180–200	2.911	0.317	0.867	0.096	0.398	0.403	0.524	421.232	17.185	422.794
200–220	2.877	0.313	0.857	0.095	0.127	0.399	0.518	423.025	16.982	415.330
220<	3.834	0.417	1.142	0.126	0.670	0.531	0.690	419.368	22.633	500.000
<i>Rainfed barley</i>										
0–10	0.564	0.061	0.168	0.019	0.000	0.078	0.102	86.376	3.332	163.930
10–20	2.040	0.222	0.607	0.067	0.005	0.283	0.367	212.835	12.042	296.281
20–30	1.750	0.191	0.521	0.058	0.000	0.242	0.315	358.906	10.333	254.236
30–40	1.578	0.172	0.470	0.052	0.474	0.219	0.284	247.479	9.315	229.187
40–50	2.092	0.228	0.623	0.069	0.004	0.290	0.376	262.960	12.348	303.793
<i>Irrigated wheat</i>										
160–180	3.951	0.391	1.161	0.118	21.260	0.050	0.711	493.801	23.322	647.000
180–200	1.748	0.391	0.599	0.118	11.843	0.022	0.314	458.638	10.318	507.700
200–220	1.454	0.391	0.525	0.118	11.157	0.018	0.262	454.013	8.583	422.340
220–240	2.695	0.391	0.841	0.118	6.618	0.034	0.485	453.885	15.908	400.000
240<	2.806	0.391	0.869	0.118	16.762	0.035	0.505	466.750	16.566	402.220
<i>Rainfed wheat</i>										
0–10	1.664	0.181	0.495	0.055	0.372	0.231	0.299	263.459	9.823	241.686
10–20	1.385	0.151	0.412	0.046	0.225	0.192	0.249	247.413	8.175	201.137
20–30	2.725	0.297	0.811	0.090	0.298	0.377	0.490	270.856	16.084	395.730
30–40	1.790	0.195	0.533	0.059	0.692	0.248	0.322	280.554	10.566	259.957
40<	3.446	0.375	1.026	0.114	0.357	0.477	0.620	284.650	20.342	500.471

The amount of important emissions for the different N fertilizer rates are shown in Table 3. These emissions were selected because earlier LCA studies have shown them to be of particular relevance for arable farming systems (e.g. Brentrup et al. 2004b; Brentrup et al. 2001; Küsters and Jenssen 1998).

The global warming potential (GWP) is used to express the contribution that gaseous emissions from arable production systems make to the environmental problem of climate change (Brentrup et al. 2004b). GWP is expressed in CO₂ equivalent (Heijungs et al. 1997; Guinée et al. 2002) and is illustrated for wheat and barley production system in Fig. 3. The highest GWP per functional unit was obtained for irrigated wheat by using 160–180 kg N/ha and rainfed wheat by using more than 40 kg N/ha, by 1,164.12 and 805.46 kg CO₂ equivalents, respectively. The most important reason to produce excessive greenhouse gases in agricultural production systems, which causes global warming, is the use of fossil fuel for machinery implementing cultivation such as plough, planting, pesticide spray and harvesting, and nitrogen fertilizer application. Barker-Reid et al. (2005) similarly, reported low emissions from a rainfed wheat crop in a temperate region of southeastern Australia where annual emissions ranged from 0.20 to 0.27 kgN₂O–N/ha (0.06–0.11 % of N fertilizer applied) depending upon tillage and fertilizer management. In the previous

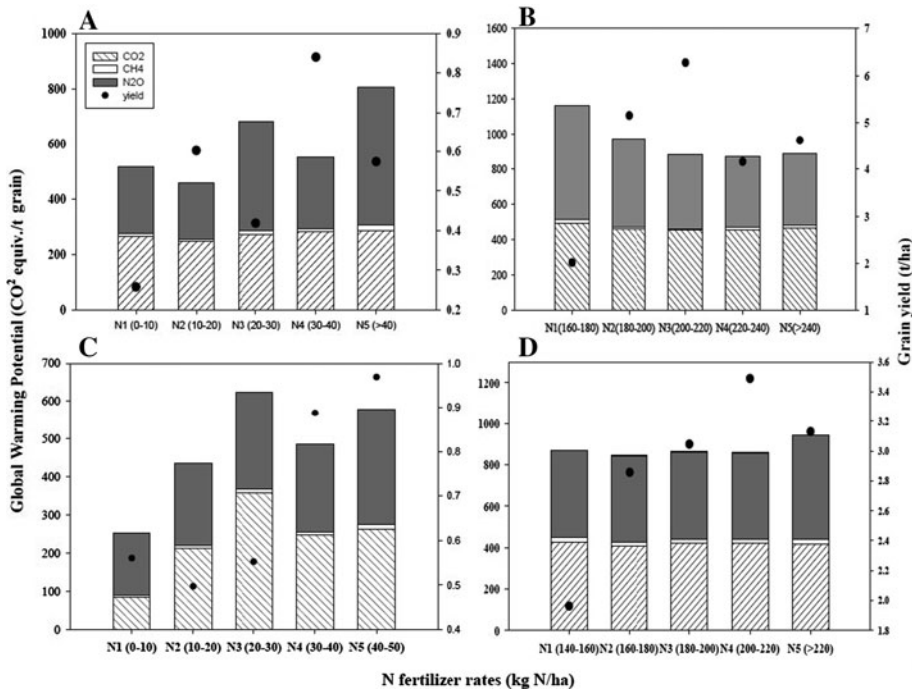


Fig. 3 Global warming potential of CH₄, NO_x, and CO₂ (CO₂ equivalent/t grain) for functional unit of rainfed wheat (a), irrigated wheat (b), rainfed barley (c), irrigated barley (d)

studies, it has been reported that on-farm emissions contribute significantly (33–54 %) to total green house gas (GHG) emissions, as a result of the application of synthetic N fertilizers to the crop (Sheehan et al. 1998; Braschkat et al. 2003). Robertson et al. (2000) also found that the emission of N₂O during the on-farm stage accounted for 77 % of the total GHG emission. N₂O emissions from land contribute significantly to ‘on-farm’ GHG emissions from wheat production in semi-arid regions (Biswas et al. 2008). The production or demand for synthetic N fertilizers, and therefore GHG emission, might be decreased by replacing chemical fertilizers with organic N fertilizers. For example, it had been suggested that ~80 % CO₂ equivalent emissions could be mitigated from the on-farm stage by substituting chemical fertilizer for organic fertilizer (Braschkat et al. 2003).

Using LCA method, Meisterling et al. (2009) investigated the organic and conventional wheat production systems in USA. They reported that, considering global warming, production of 1 kg bread under organic system resulted in production of 30 kg CO₂ equivalents, which is less than the conventional cropping system. Nitrous oxide (N₂O) concentration in the earth’s atmosphere has increased from 275 to 319 ng/g since the industrial revolution (Dentener et al. 2001; Houghton et al. 2001). This is of concern as N₂O contributes to global warming and destruction of the ozone layer. Although N₂O is only present as a trace gas in the earth’s atmosphere, it has 310 times the global warming potential of carbon dioxide (CO₂) and a lifespan of 120 years (Crutzen 1981). N₂O emissions from agricultural soils are considered to account for 70–81 % of the increase in the earth’s atmosphere, which has been linked to a global increase in nitrogen (N) fertilizer use (Bouwman 1990). Life cycle assessment can be undertaken to account for all GHGs

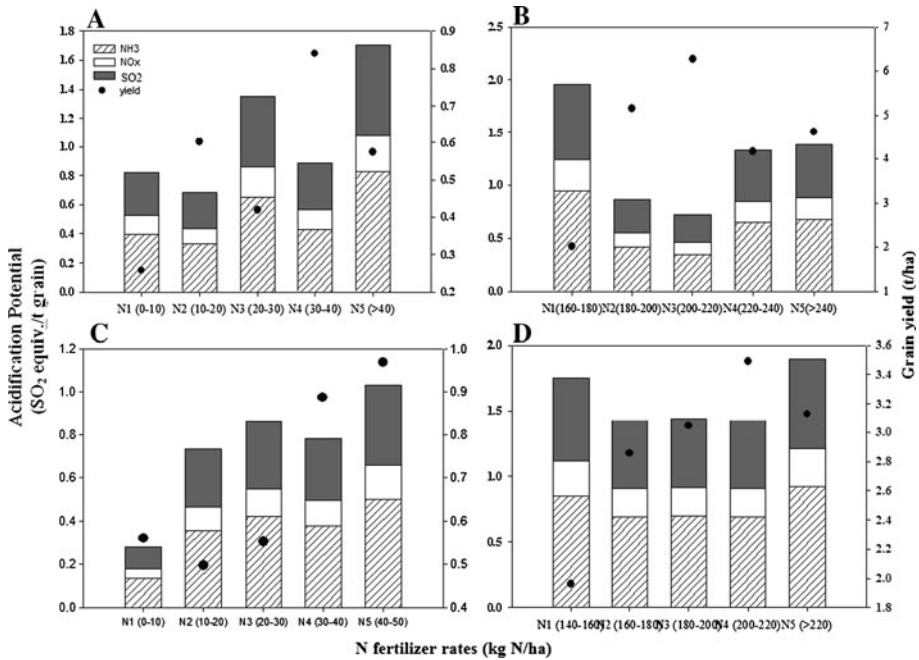


Fig. 4 Acidification potential of NO_x, SO₂, NH₄ (SO₂ equivalent/t grain) for functional unit of rainfed wheat (a), irrigated wheat (b), rainfed barley (c), irrigated barley (d)

emitted for crop production so that mitigation strategies focus on the primary sources of GHG emissions (Biswas et al. 2008).

Acidification potential per functional unit of wheat and barley production systems expressed in Kg SO₂ equivalents is illustrated in Fig. 4. The highest acidification potential per functional unit was assigned to irrigated wheat using 160–180 kg N/ha and rainfed wheat by using more than 40 kg N/ha, which are 1.95 and 1.70 kg SO₂ equivalents, respectively. Furthermore, the acidification for irrigated barley at the rate of 220 kg N/ha and rainfed barley at the rate of N more than 40–50 kg/ha were 1.89 and 1.03, respectively. Excessive use of N fertilizers for wheat and barley production systems increases gas emission and consequently increases the risk of acidification. In this regard, due to volatilization after N fertilizer application, the emission of NH₄ linearly increases by increasing the amount of N fertilizer. In rainfed wheat and barley, respectively, 48.4 and 48.5 % of total acidification gases was related to NH₄ emissions, 15.1 % in both rainfed wheat and barley was related to nitrogen oxides, and the rest portion in rainfed wheat (36.3 %) and barley (35.9 %) was assigned by SO₂. Haas et al. (2001), using LCA methodology to investigate three pasture management methods, reported that pastures under organic management compared to conventional management resulted in less energy consumption, impact on global warming and soil acidification. Haas et al. (2001) reported acidification potentials of 119 kg SO₂ eq and 136 kg SO₂ eq ha⁻¹ for an intensified dairy farming system and an intensive one, respectively, considering ammonia emissions to occur only during the storage and application of manure. Using an area-based FU favored the intensified system, which had a lower stocking rate (livestock unit ha⁻¹). Expressing these

results per 1,000 kg of milk yields acidification potentials of 13 kg SO₂ eq and 14 kg SO₂ eq for the intensive and extensified systems, respectively.

Eutrophication for different production systems is demonstrated in Fig. 5. The grain yield of irrigated wheat at the rate of 160–180 kg N/ha application and rainfed barley at 140–160 kg N/ha, despite utilizing high level of N fertilizer, is low. Consequently, this low yield in spite of high input makes excessive amount of compounds such as NH₄ to release which bringing about eutrophication. In both irrigated wheat and barley production systems, the highest grain yield was obtained when 200–220 kg N/ha was applied. Therefore, in these production systems because of the highest uptake of utilized fertilizer through crops, eutrophication potential was at the lowest level. Similar situation was observed under rainfed systems, as the lowest eutrophication potential per functional unit was registered for rainfed production system when 30–40 kg N/ha was applied (Fig. 4). Hospido et al. (2003) estimated the eutrophication potential of 1,000 L of packaged liquid milk to 5.31 kg PO₄ eq of which 73 % originated from dairy feed production. Since the production of 1,000 L of raw milk required the ingestion of 1,303 kg of feed, their eutrophication potential was equivalent to 3.0 kg PO₄ eq per 1,000 kg of feed.

The normalized indices of each impact category for different production systems are shown in Fig. 5. Accordingly, the highest value as impact on environment was obtained under intensive irrigated production system. Global warming potential showed the highest impact among other environmental impact, whereas, in other production systems, eutrophication indicated the greatest impact (Fig. 5).

In order to compare all environmental impact related to each production system, the resulting normalized indicator values related to each impact category were weighted and EcoX calculated for each system (Fig. 6). Our results showed that, among different wheat

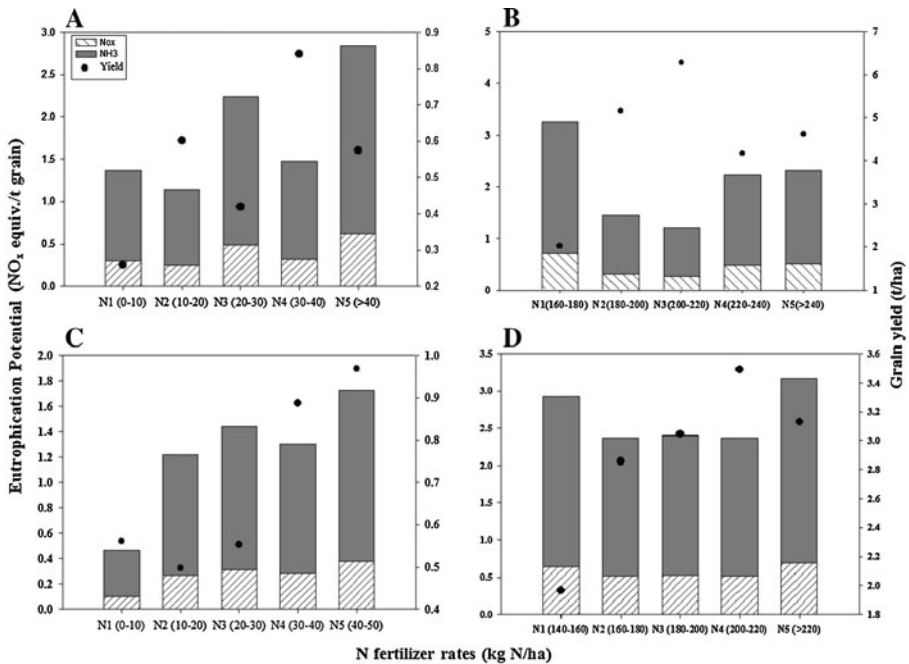


Fig. 5 Eutrophication potential (NO_x equiv./t grain) of different contaminants for functional unit of rainfed wheat (a), irrigated wheat (b), rainfed barley (c), irrigated barley (d)

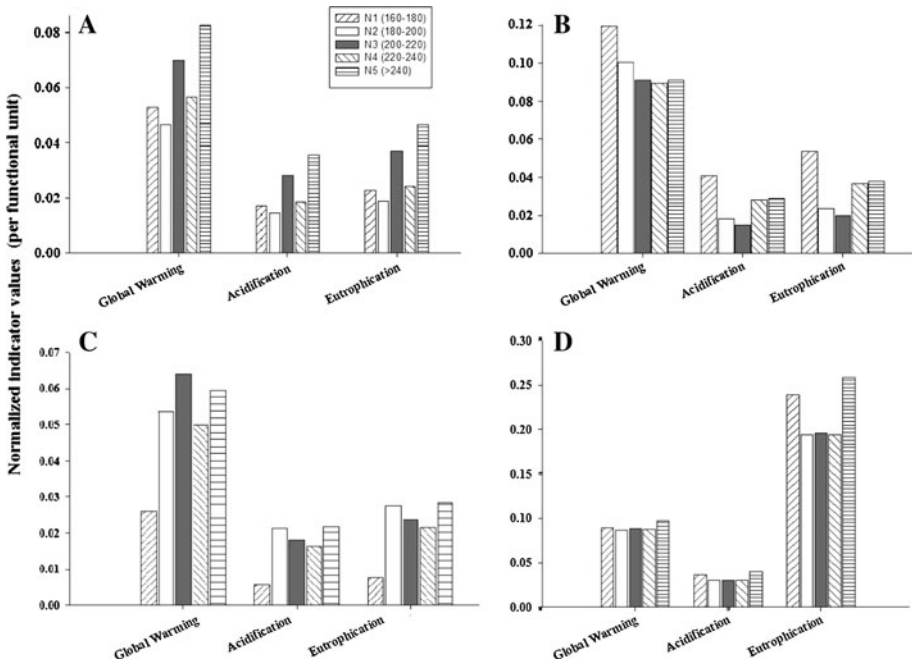


Fig. 6 Normalized indicator values for each impact category of rainfed wheat (a), irrigated wheat (b), rainfed barley (c), irrigated barley (d)

production systems investigated in this study, irrigated wheat by application 200–240 N kg/ha and irrigated barley using 200–220 N Kg/ha represented the least environmental impact (Fig. 6).

In this study, aggregated environmental impacts of both irrigated wheat and barley systems were calculated at the range of 0.024–0.174 and 0.049–0.34, respectively, and also aggregated environmental impacts of rainfed wheat and barley systems were at the range of 0.01–0.37 and 0.021–0.21, respectively.

There are a lot of studies that dealt with the LCA of single crops. Brentrup et al. (2004b) used LCA method to assess the winter wheat production impact on environment under different nitrogen consumption levels. They reported that, by consuming nitrogen less than 150 kg/ha, aggregated environmental indicator (Eco-X) was about 0.22–0.26 per 1 ton wheat production. By increasing nitrogen fertilizer rate from 200 to 390 kg/ha, Eco-X changed by 33–100 % more than when less nitrogen was applied. However, results showed that, the land use and eutrophication had the lowest and highest effect on Eco-X factor, respectively. Using LCA methodology, Iriarte et al. (2010) investigated the impact of sunflower and rapeseed farming systems on environment conditions. They categorized sunflower production systems impact such as greenhouse gases emission and eutrophication. They reported that in both categories, production and consumption of chemical fertilizers imposed the most adverse impact on environment. The research result on the relationship between agricultural intensity and the environmental impact in greenhouse tomato cultivation was illustrated that the degree of the environmental impact per hectare correlates with the intensity (intensive cultivation has a greater impact on the environment) and that the degree of environmental impact per kilogram of fruits inversely correlates with

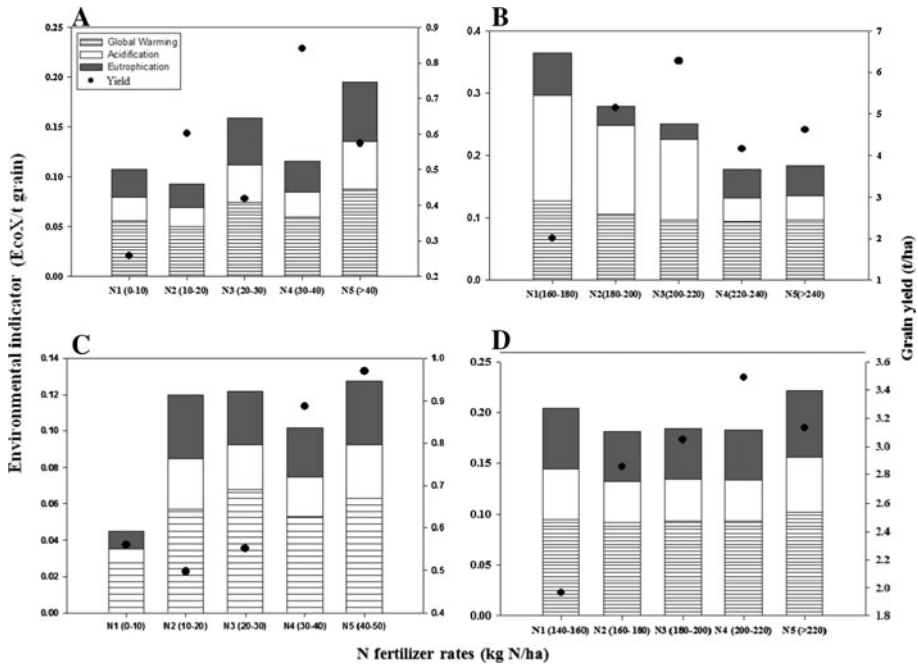


Fig. 7 Aggregated environmental indicator values (Eco-X) per ton of grain (*stacked bars*) and yield (t/ha, *dots*) at increasing N fertilizer rates for rainfed wheat (**a**), irrigated wheat (**b**), rainfed barley (**c**), irrigated barley (**d**)

the intensity (extensive cultivation has a greater impact) (Hayashi 2005). In this case, the intensity was measured by applied nitrogen (kg/ha), and the environmental impact was measured by global warming potential expressed as kg CO₂ equivalence (Fig. 7).

4 Conclusion

Results represented that, agricultural production systems with high level of yield do not always contradict environmental safety. In other word, high yield in agriculture and environmental stewardship is not divergent. On the other hand, excessive use of N fertilizer taking its adverse impact on resource uses efficiency into consideration, increase environmental impact. Therefore, one of the appropriate approaches to decline the environmental impact of agricultural production is achieving higher yield per unit of area by increasing resource use efficiency. The most important goal of any life cycle study is, of course, to improve and optimize the system. Based on the study carried out, we have identified parts of the life cycle that are critical to the total environmental impact as well as some major gaps in the available data.

In conclusion, in order to decrease environmental impact and obtain an environmental friendly wheat and barley production system, different methods could be proposed including N application on the basis of crops demands to provide utmost uptake and consequently decrease nutrients leaching, decrease acidification and eutrophication impact, and decrease NO_x emissions through decrease in NH₄ volatilization to diminish global warming potential. For instance, organic inputs are always recommended as alternatives to

the mineral fertilizers. Rather than chemical fertilizers, organic amendments have been suggested as a method for 'low input agriculture' to achieve sustainability in dry land agriculture. Several low input techniques (Ichir et al. 2003) to regenerate soil fertility are based on the incorporation of organic matter into the soil.

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