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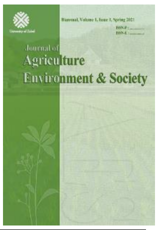

Comparison of environmental impact assessment between irrigated and rainfed wheat using the life-cycle assessment method (LCA): The case of Khorramabad, Iran

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ABSTRACT

The life-cycle assessment of two irrigated and rainfed wheat crops was investigated in this study. Tillage, planting, irrigation, fertilization, pesticide spraying, and harvesting are the basic stages of production for each crop throughout its life cycle. A farmer's questionnaire was used to collect farm data. The ecoinvent models compile emissions in their reports. The functional unit is designed to produce one ton of grain. Following the calculation, emissions from each stage of production in a triple environment (soil, water, and atmosphere) are logged. Following that, a life-cycle impact assessment, or LCIA, was carried out. The environmental effects were first estimated separately for each crop, followed by a comparison of the two crops. The calculated potential for each ton of irrigated wheat equals 860 Kg of CO_2 equivalent in the impact assessment of global warming, whereas it is 623 Kg for rainfed wheat. The production potential per ton for the eutrophication phenomenon is roughly equivalent for both systems: 2.625 equivalent Kg po4 for irrigated wheat and 2.601 for rainfed wheat. The data from the long-term scenario show an increase in the potential for eutrophication in both crop productions. Meanwhile, the long-term effects of chemical fertilizer use on human health and aquatic and terrestrial ecosystems indicated a potential increase in their use. Following a data uncertainty analysis, it was determined that, with a confidence interval of 95 percent, details of the life-cycle assessment results could be applied to the farms under consideration. However, some of the environmental impacts in the uncertainty analysis overlap. The highest overlapping values are insufficient to call average farm results into question.

1. Introduction

Given the importance of environmental principles in production and agricultural processes, the most important option for justifying farmers is to introduce environmental impacts into production. Sustainability must be considered in terms of environmental conditions along with economic and social issues. Therefore, achieving sustainability or taking steps in this way involves taking into account the complexities of these three pillars and their interactions (Brentrup et al., 2004a; Hassani et al., 2016).

Life-cycle Assessment (LCA) is a standard method (ISO 14040, 2006) that is considered in this study. Applying LCA in the farm framework requires data on the inputs the farmer places on the crops and on the outputs he receives, which measures the effects that will remain in place (Brentrup et al., 2004b). The impact assessment is done in accordance with the elaborated inventory, which ultimately can be interpreted by these panels as being useful to others and making decisions based on them (McGregor, 2002).

Determining a functional unit in the life-cycle analysis can be effective. A functional unit is a reference that interconnects the input and output of a produced crop. With such a unit, the researcher can compare different systems of different structures based on a common basis (Sonesson et al., 2010). The amount of inputs (including fossil fuels and mineral fertilizers), production and transfer of agricultural inputs (such as fertilizer

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production), and field operations (such as tillage and harvesting) for a functional unit should be determined (Khorramdel, 2011).

Many researchers have argued that LCA is a method for quantifying the environmental performance of products. The numerical ranking of this method enables the environmental performance of crops to be analyzed from the aspects of climate change, ozone depletion, acidification, eutrophication, depletion of energy sources, and other environmental impact groups. In this study model, inputs were collected based on data on the use of chemical fertilizers, machinery, fossil fuels, and other inputs for two crops (Smaielpoor et al., 2015).

The review of the life-cycle assessment should include the definition of the purpose and scope, the analysis of the inventory, the impact assessment, and the interpretation of the results. The interpretation of the results is associated with all the mandatory stages of the life-cycle. Therefore, the scientific and methodological determination of the various stages of the life cycle contributes to the emergence of a scientific interpretation. To set a life-cycle inventory according to the purpose and scope set, the attitude towards key issues is very important (Smaielpoor et al., 2015; Mir Haji et al., 2012; Khorramdel et al., 2015; Hosainzade et al., 2010). With regard to production inputs and how they can be used, they can be manipulated with scientific management to produce crops with the least environmental emissions. It should not be forgotten that natural resources will be exhausted, and any measures to preserve and conserve these resources will increase human healthy life on this planet.

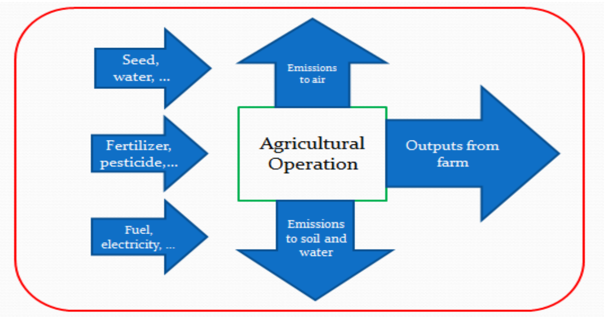

Figure 1. System boundary

This study tries to investigate the differences between the two wheat production methods in the study area. In the rainfed wheat production method, water and electrical energy are not consumed. Differences in intake and inputs are also seen. Amounts of labor, machinery and land occupation are different for a given functional unit. In spite of many differences in the production process, this paper examines the differences that may exist in environmental impacts.

Data uncertainty analysis has been performed to evaluate more precisely and clarify the differences between the two crops; many of the differences that are being examined through the average data may not be the same for all farms.

2. Materials and methods

2.1. Study area

The study area is Khorramabad in the semi-arid Lorestan province of Iran. The city is located at 48°21´ N, 32°3´ E, at 1117 m above sea level. The average annual precipitation is 524 mm, and the average annual temperature is 17 °C. In this area, a lot of irrigation water is provided by wells. A mountainous region where steep land is abundant. Water resources suitable for dry farming have led farmers to use rainfed wheat on steep lands.

2.2. Life-cycle Assessment methodology

This part describes the steps of the LCA process and the data gathered for this study.

2.2.1. Goal and scope

2.2.1.1. Defining the goal of this study

The goal of this study was to evaluate the environmental effects of irrigated and rainfed wheat crops in the study area. The purpose of this study is to determine how the damage caused by the cultivation of these crops will enter the environment.

Identifying and simulating environmental impacts in the study area will help farmers to understand and have a better perception of reducing environmental impacts.

2.2.1.2. System boundary

The boundary defined for this experiment is the farm framework. Data information is collected in a farm context. A flowchart is presented to better understand the data collection process and the system boundary (Figure 1).

Flowchart information includes an overview of inputs, outputs, agricultural operations, and emissions. All components of the LCA will be defined in this scope, and the final stage of the interpretation will be presented in this scope.

2.2.1.3. Functional unit

Functional unit is a reference used to compare different systems based on a common structure (Wiedemann and Mcgahan, 2011).

The selected functional unit was one ton of harvested grain. All stages of agricultural operations, inputs, and emissions are calculated for this functional unit.

2.2.2. Life-cycle inventory (LCI)

In the inventory stage, all the inputs of the cropping system are accurately described, as are all the outputs and emissions to the triple environments. Different stages have been defined for the production of irrigated and rainfed wheat. Information about the various stages of production of crops is given in Table1.

2.2.3. Impact assessment

In the present research, the main goal is to investigate the environmental impacts of the crops, so the impact chains in relation to the impact assessment have been selected along with the European series of guidelines. In this study, the CML Recipe command was used for evaluation. These environmental impacts are first examined separately during the life-cycle assessment of the two crops and then compared.

Each impact assessment has an abbreviation and an equivalent unit that is available in Table 2 (Goedkoop et al., 2008, Pre consultants, 2003, Ahmadi and Ghasempour, 2016).

Table 1. Agricultural operations defined, according to relevant inputs

Agricultural operation	Tools and materials	Other information
Tillage	Plough, rotary cultivator, tractor made is Massey Ferguson 285 (75 hp), diesel	Tractor weight (2746 kg), plough (360 kg), rotary cultivator (600 kg)
Planting	Planter, tractor (75 hp), diesel, seed, pesticide for disinfection	Planter for wheat (680 kg) for non-irr wheat (700 kg)
Irrigation	Water pump (40 kw), electrical energy, labor	Just for wheat, water use in well (865.67 m^3)
Fertilization	Urea, triple super phosphate, Potassium sulfate, tractor (75 hp), sprayer, diesel	Fertilizer sprayer (350 kg)
Plant protection	pesticide, sprayer, tractor (75 hp),	Sprayer (380 kg) and Vol. (400 lit)
Harvest	Combine, truck, diesel	Combine (105 hp) and (2600 kg), Tank vol. (2700 lit)

Farm inputs in this system are environmental inputs (water, carbon dioxide in the air, land occupation, etc.), Technosphere inputs (tools, materials, machinery, etc.), and energy inputs (electricity, fossil fuels, etc.).

2.2.4. Interpretation

There are several basic elements in the life-cycle interpretation that, in their view, can provide an acceptable interpretation by the researcher. These elements can be categorized as follows:

- Identify important issues based on the results of the life-cycle inventory in process and the assessment of this inventory in the overall life-cycle assessment.
- An assessment that considers completeness, sensitivity, and consistency.
- Finally, make conclusions, limitations, and recommendations.

2.3. Investigating uncertainty of data

Due to the fact that the test data is collected from different farms, it's not possible to announce the results with certainty for all of the farms. Some farms receive more inputs than others, and due to this difference, environmental damage can also be different. In this study, an uncertainty analysis was performed using the Monte Carlo method to compare the two systems. The confidence interval in the uncertainty analysis is 95%. The distribution used in this analysis is the Monte Carlo method.

2.4. Source of emission data

The calculation of emissions is intended for the three environmental compartments: soil, water, and atmosphere. A summary of the types of emissions and their sources is given in Table 2.

Table 2. Impact scores - equivalent units and specifications

Impact assessment	Unit	comment
Natural resources depletion, abiotic (AD)	kg Sb equivalent.	This potential consists in the consumption of renewable and non-renewable resources.
Abiotic depletion, fossil fuels (ADF)	MJ	Exploitation of fossil fuels, mineral resource and also the potential of fossil resource depletion.
Global warming potential (GWP)	Kg CO2 equivalent	Potential share of one material in greenhouse emissions impact.
Ozone layer depletion (ODP)	kg CFC-11 equivalent	Value of ozone layer destruction, which is mainly created by hydrocarbons including carbon, chlorine and fluorine.
Human toxicity potential (HTP)	kg 1,4-DB equivalent	Damage potential of one unit of released chemical material to the environment based on the toxicity of a combination and its potential of consumption dose.
Terrestrial eco-toxicity (TE)	kg 1,4-DB equivalent	Emissions of toxic substances to soil.
Fresh-water aquatic eco-toxicity (FEW)	kg 1,4-DB equivalent	Emissions of toxic substances to fresh water.
Marine eco-toxicity (ME)	kg 1,4-DB equivalent	Refers to impacts of toxic substances on marine ecosystems.
Photochemical oxidation (PO)	kg C2H4	The potential has is expressed as the creation of the one capacity of ozone of volatile organic material for ozone production.
Acidification (AC)	kg SO2 equivalent	The potential shows the acidification impact of SO_2. Another material that has been recognized as acidification, is nitrogen oxide and ammonium. Also the impact of SO_x is similar to SO_2
Eutrophication (EU)	kg PO_4^{-2} equivalent	The potential was used based on PO_4^{-2} , another emission of eutrophication were nitrogen oxidation N_2O and ammonium NH^{4+}

Table 3. Data sources for emission to the triple environment

Compartment	Emissions	Data sources
Atmosphere	NH_3, CO_2, N_2O, NO_X, SO_2, CH_4, CO, etc.	Bengona et al., 2015. Nemecek and Kagi, 2007.Nemecek and Schntzer, 2011c. Agrommon, 2009.
Water	Nitrate, phosphate, cadmium, lead, zinc, etc.	Bengona et al., 2015. Nemecek and Kagi, 2007. Nemecek and Schntzer, 2011b. The emission model SALCA-P & SALCA-NO_3, 2006.
Soil	Cadmium, lead, zinc, etc.	Nemecek and Kagi 2007. Nemecek and Schntzer, 2011a. Robert and Stauffer, 1996.

2.5. Database and software

The global database used in this study is the ecoinvent database. The database is reviewed and updated over time, with the latest version being version 3 at the time of the current research. The ecoinvent 3 has more different models and methods than the ecoinvent 2. Documents related to this extension and the changes are available on the site. The SimaPro software used for the life-cycle assessment method describes the software version and specifications below. SimaPro 8, report version V3, language: English.

3. Results and discussion

3.1. Irrigated wheat life cycle assessment

Rainfed wheat is also a cereal for cultivation in the study area. Therefore, in terms of cultivation, it follows a completely observable process with wheat. Most of the items used are the same, and the difference in the production stages is due to the lack of irrigation in rainfed wheat.

The results of the evaluation of the wheat life-cycle assessment production are in accordance with Table 3. The various stages of wheat production are tillage planting, fertilizing, irrigation, pesticide spraying, and harvesting. Figure 2 shows the percentage of production steps for each potential impact.

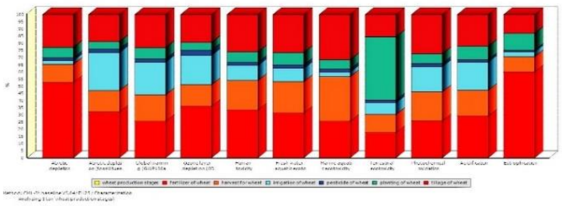

Figure 2. Contribution of irrigated wheat production steps to midpoint impact indicators

According to the results of the data analysis, the most impactful steps for abiotic and fossil fuel depletion are due to fertilization and to the use of chemical fertilizers. The greatest impact on fertilization operations can be seen in the potential impact of eutrophication. Tillage operations have significant effects on the majority of impact assessments.

3.2. Rainfed wheat life-cycle assessment

The results of the rainfed wheat are shown in Table 4. Different stages of rainfed wheat production include tillage, planting, fertilizing, pesticide spraying, and harvesting. Fewer inputs have been used in rainfed wheat. In Figure 3, the percentage of production stages is shown for different environmental impacts. Due to the lack of irrigation in rainfed wheat, the planting process has the greatest impact on the environmental damage of the terrestrial ecosystem.

For the other stages, the same tendencies as with irrigated wheat are observed (Figure 3 and Table 5).

The risk of increasing nitrate levels in groundwater and the potential for eutrophication in the fall and winter months when rainfall is often or always more than the absorption of plants (Stauffer et al., 2001).

Table 4. Environmental damage resulting from the production of one ton irrigated wheat

Impact assessment	Unit	Amount
Abiotic depletion	Kg Sb eq	0.005815
Abiotic depletion (fossil fuels)	Mj	11709.96
Global warming (GWP100a)	Kg CO_2 eq	860.6032
Ozone layer depletion	Kg CFC eq	0.000101
Human toxicity	Kg 1,4-DB eq	445.1575
.Fresh water aquatic eco-toxicity	Kg 1,4-DB eq	207.227
Marine aquatic eco-toxicity	Kg 1,4-DB eq	1408588
Terrestrial eco-toxicity	Kg 1,4-DB eq	3.452
Photochemical oxidation	Kg C_2H_4 eq	0.2707
Acidification	Kg so_2 eq	5.659
Eutrophication	Kg Po_4 eq	2.625

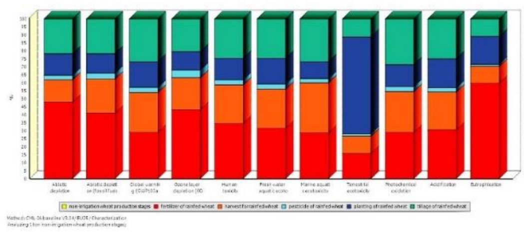

Figure 3. Contribution of rainfed wheat production steps to midpoint impact indicators

3.3. Comparison between both systems

To compare the two systems, many items are considered. Due to the fact that there is no irrigation in rainfed wheat, the first five common stages were surveyed (Figure 4).

The presence of similar inputs in the two systems makes comparisons easier. Initially, environmental inputs are required. With the yield being lower in the rainfed system, land occupancy is greater, and inputs per ton should be also increased.

The next issue to be taken into consideration is the difference in technological inputs required to produce one ton of grain. When more land is occupied for production, mechanization also increases. As a result of fossil fuels, machinery depreciation and environmental emissions increase. Figure 4 highlights the difference between the producing stages for one ton of wheat in irrigated and rainfed systems.

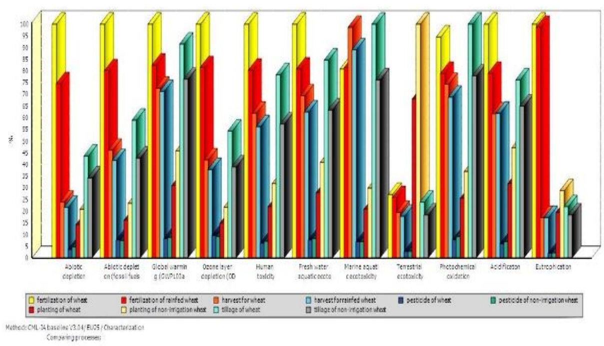

Figure 4. Comparison of the stages of production of irrigated and rainfed wheat

(normalized by the most impacting stage for each potential impact)

From the diagram, it is quite clear that the use of chemical fertilizers in the two models of planting has the greatest effect on eutrophication potential. Nevertheless, the effect of fertilizer use in the irrigated system is slightly higher than that of the rainfed one. Eutrophication potential is calculated on the basis of PO4. among other emissions affecting eutrophication, nitrogen oxides (N_2O) and ammonium $NH4^+$ can be mentioned. Eutrophication is the unintentional increase in the production of biomass in terrestrial and aquatic ecosystems due to the entry of nutrients, which can change the composition of plant species. Eutrophication is particularly dangerous in surface waters, as it can exacerbate the growth of algae and lead to the loss of life in ponds and lakes (Brentrup et al., 2004a).

According to Figure 4, the planting process has the greatest impact on the toxicity of the terrestrial ecosystem. The effect of rainfed wheat planting is greater on terrestrial ecosystem eco-toxicity. The probability of these results may be due to the phenomenon of occupied land. Farmers choose land and farming according to their assets and financial level. Drought fields in Khorramabad are located on more slopes, except for the farmer's assets. Irrigated agriculture is not possible on these lands or financially, it does not meet the costs of the farmer (Hassani and Ramroodi, 2017). Therefore, land occupation is higher for a ton of rainfed wheat and will cause a wider range of damage to the terrestrial ecosystem.

The use of chemical fertilizers has a significant impact on abiotic depletion, and rainfed wheat is more effective in terms of abiotic resource and fossil fuel impacts. In the impact assessment of marine aquatic eco-toxicity, the stage of tillage and harvesting is very influential. Compared to the two systems, they have a significantly higher effect on the irrigated one.

In terms of global warming potential, the fertilization, tillage, and harvesting stages have the most effect, respectively. Similarly, a lesser degree of ozone depletion is also observed. In two stages of fertilization and tillage, the impact of producing one ton of wheat is more than one ton of rainfed wheat in terms of global warming and the ozone depletion potential. The results indicate a great similarity in the effect of the harvesting stage for the two cropping systems. Other comparisons between the stages of production and the impact assessment are clearly evident in Figure 4.

3.4. Uncertainty analysis

After evaluating the test data using the uncertainty method, the results are shown to have a greater difference than the life-cycle assessment comparison. The method chosen to assess uncertainty is the use of the Monte Carlo distribution. The assumed confidence interval is 95%. Chart uncertainty comparing wheat and non-irrigated wheat is available in Figure 5.

The results presented in the chart above show uncertainty comparisons of 11 environmental impacts for both systems. The results of this analysis show that 95% of the environmental impacts of irrigated wheat are greater than or equal to rainfed wheat, and in all environmental impacts, this is a priority.

It should be noted that the percentage of cases where rainfed impacts are higher than irrigated impacts is not negligible. Therefore, there may be potential for further damage to the environment in some rainfed wheat fields. Accordingly, the environmental effects of eutrophication, global warming, acidification, abiotic depletion, and photochemical oxidation cause the highest occurrence of this inversion.

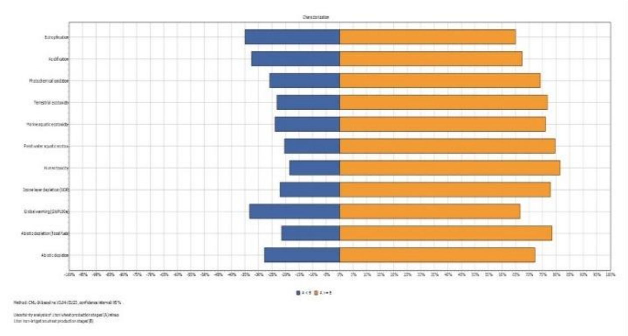

Figure 5. Results of uncertainty assessment of environmental impacts for one ton of wheat. A: irrigated wheat, B: non irrigated wheat. 95% confidence interval

To better understand this result, the results of the uncertainty caused by the phenomenon of eutrophication are expanded. Figure 6 shows the comparison of the two systems in this environmental impact.

In the chart above, the data uncertainty range is quite clear. The values are similar to the mean in the graph, around the red dot. Due to the increase in the effect of eutrophication in A (irrigated), many datasets with high similarity and even more in the range of product B (rainfed) are seen. Therefore, it is not correct to say with certainty that the potential for eutrophication of one ton of irrigated wheat is always higher than one ton of rainfed wheat. In the rest of the environmental impacts mentioned, this overlap is much lower, and so producing irrigated wheat has more potential to produce environmental damage.

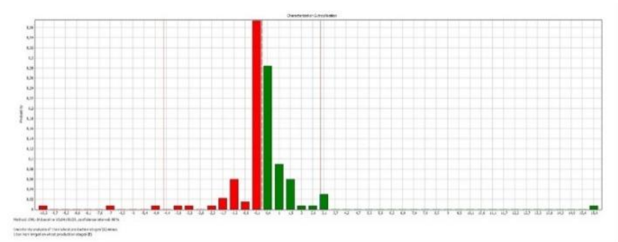

Figure 6. Comparison of the uncertainty of eutrophication in the production of one ton of irrigated and rainfed wheat. 95% confidence interval. Red: irrigated system data, Green: rainfed system data

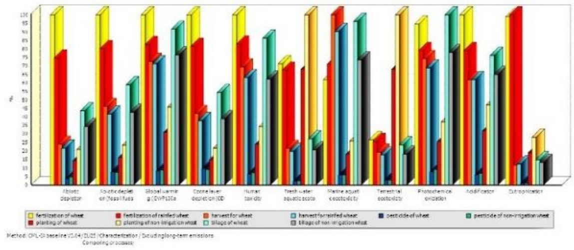

Figure 7. Comparison long-term emissions of irrigated and rainfed wheat production

3.5. Long-term emissions

One of the capabilities of the SimaPro software is its long-term environmental impact calculations. Looking at Figure 7 and comparing it with Figure 4, the differences created over time are specific. The severity of the difference in impact assessment groups will be different, and in some cases, there will be no significant difference.

In this assessment over the long-term, the effects of fertilization on the eutrophication indicator have increased for rainfed wheat. The next step is to increase the impact of the planting process on the freshwater aquatic eco-toxicity, which increases over time. Initially, it had the greatest impact on marine aquatic eco-toxicity, but in the long-term, it also affects freshwater aquatic eco-toxicity.

An important issue is the increased environmental damage caused by the increased effects of human toxicity during the tillage and harvesting stages. The emission of these two processes will, in the long-term, increase the severity of harm to human societies. In the impact assessment of human toxicity, the increase in fertilization rate in rainfed wheat is also known. Indeed increasing the number of emissions related to the tillage process and harvesting in the two systems in the long-term will affect human toxicity more.

4. Conclusions

4.1. Life-cycle assessment results

The global food production process and the emissions of agricultural processes intensify the effects of eutrophication and acidification phenomena and increase global warming and climate change (Saarinen et al., 2012). In recent years, researchers have increasingly used life-cycle assessment to identify environmental impacts so that they may be able to come up with ways to produce beneficial food (Notarnicola et al., 2012).

Actions that prevent soil erosion are effective in reducing environmental impacts. Like green manure, due to the reduction of soil erosion, nutrients enter the soil and eventually lead to less use of chemical fertilizers (LBL et al., 2000).

The production of food through agricultural processes involves pollutant emissions into the environment. For example, ammonia (NH_3) can be released, accounting for about 93% of the agricultural process (Thoni et al., 2007), methane (CH_4), nitrate (NO_3^-), etc. (Nemecek and Kagi, 2007). Ammonium (NH_4^+) in the chemical fertilizers used in the agricultural process can easily be converted into ammonia (NH_3) and released into the air. Agriculture has been evaluated in Switzerland as the largest ammonia production process (Thoni et al., 2007, Nemecek and Schntzer, 2012).

The major findings of this project are the following:

1- The difference between the global warming potential of irrigated and rainfed wheat is probably due to irrigation in rainfed wheat. This difference could be due to the lack of electricity in the energy section of the life-cycle inventory and the lack of water in the environmental inputs set in the life-cycle inventory.

2- Rainfed wheat may have even higher global warming and greenhouse gas emissions than wheat in the event of irrigation because the land used to produce rainfed wheat is steeper (from the information collected in the field questionnaire) and because the functioning of the machinery to produce one ton of cereal is longer and uses more fossil fuel.

3- Considering emissions affect environmental impacts in the long term, most research findings are based on one year of production. Over time, the accumulation of emissions from previous years can make the environmental situation more unpredictable.

4- According to the scenario, the impact of long-term emissions on the environmental impact of human health is quite evident. It should be noted that other environmental impacts of aquatic and terrestrial ecosystems are also affected.

5- Considering the small difference in environmental potential between irrigated wheat and rainfed wheat, the irrigated system may be more suitable in the studied area. Due to the weather conditions in this upland, more energy and hours of operation are needed for rainfed wheat.

Irrigated wheat on flat land and suitable conditions may have a lower environmental impact. According to the findings, the land selection is important for different agricultural processes.

Regarding mechanization and field operations, topographic conditions should also be considered in land use planning. Government infrastructure, especially in third-world countries, is important for supporting farmers. Changing the attitude of farmers towards the environment and the pursuit of nature-friendly can help achieve sustainability indicators.

4.2. Results of uncertainty analysis

After uncertainty analysis of the data, it became clear that, with a confidence interval of 95%, details of the results of the life-cycle assessment could be applied to the studied farms. Although there are some cases with higher impacts for rainfed wheat, the ratio between the cases where the irrigated system has more impact (relatively to the rainfed system) confirms the results of the average farms. The most critical case appears to have eutrophication potential.

The results of the inventory analysis of both cropping systems showed that the fertilization operation had the highest effect on this environmental indicator. Fertilization operations are planned according to the farm area. Therefore, products with a lower yield will receive more inputs to produce a functional unit.

Table 5. Environmental damage resulting from the production of one ton rainfed wheat

Impact assessment	Unit	Amount
Abiotic depletion	Kg sb eq	0.004619
Abiotic depletion (fossil fuels)	Mj	7291.318
Global warming (GWP100a)	Kg CO_2 eq	620.2596
Ozone layer depletion	Kg CFC eq	6.83E-5
Human toxicity	Kg 1,4-DB eq	339.3906
Fresh water aquatic eco-toxicity	Kg 1,4-DB eq	164.2487
Marine aquatic eco-toxicity	Kg 1,4-DB eq	1252330
Terrestrial eco-toxicity	Kg 1,4-DB eq	3.762
Photochemical oxidation	Kg C_2H_4 eq	0.1976
Acidification	Kg so_2 eq	4.067
Eutrophication	Kg po_4 eq	2.542

4.3. Conclusion

The activity of farmers as food producers should be appreciated. Paying attention to this hardworking class and trying to modify their production processes is very beneficial for the future of food and the resources of the planet. In order for humans to live longer on Earth, they need to understand the principles of the state of resources and modify their pattern of consumption.

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