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Research Article

ASSESSMENT OF SUSTAINABILITY INDICES IN MAIZE, BARLEY AND WHEAT BASE ON NITROGEN DYNAMICS IN NEYSHABUR

Zahra Mohammadzade and *Amir Behzad Bazrgar
Department of Agronomy, Neyshabur Branch, Islamic Azad University, Neyshabur, Iran
**Author for Correspondence*

ABSTRACT
The study was conducted to investigate the sustainability indices of maize, barley and wheat using a simulation model at Neyshabur environmental condition. All production information of these crops gathered and recorded during 2012 and 2013 growing seasons. Nitrogen losses simulated using SUNDIAL model. Sustainability indices use efficiency and environmental impacts of each crop estimated using N-Loss model. Results showed that the highest nitrogen loss during crop production belonged to NH3volatilization and 73, 64 and 63 percent of nitrogen loss belonged to NH3 volatilization in maize, barley and wheat respectively. The second nitrogen loss factor was leaching in maize (19%) and denitrification in barley (25%) and wheat (26%). Total nitrogen loss in maize, barley and wheat was 48, 31 and 26 kg nitrogen per hectare, which showed the importance of better fertilization management in order to enhance nitrogen use efficiency. Nitrogen loss to air and soil in maize production was lower than barley and wheat. Results showed that barley and wheat had low nitrogen use efficiency and high environmental impacts despite are sustainable in respect of soil nitrogen content.

Keywords: *Environmental Impacts, Nitrogen Loss, Leaching, Denitrification, Sustainability Indices, Sundial*

INTRODUCTION
Food supply for enhancing world population is the most important challenge of humanity. The challenge is more vital in unsuitable environmental conditions for crop production such as Iran drought and semi drought regions. Population growth during last decades resulted in overconsumption of natural resources especially in developing countries. Although this overconsumption resulted in more food production in short term, but had vast environmental impacts. Add to these reduced harvested areas around the world results in more industrial and intensive farming which has negative impacts on environment. Production stability in drought environments is depended on preserving resources such as soil and water. Thus enhancing agricultural and food production systems efficiency is necessary. Modern agro-ecosystems most manage to produce high yield in short term and show sustainability in long term.
Currently in agro-ecosystems high yield usually gains by higher input consumption. Nitrogen is one of the most important inputs in agriculture. Just a few more than 50% of total consumed nitrogen fertilizers uses effectively in agricultural production and the rest scatters in environment and results in environmental pollution (Galloway *et al.*, 2008). Different shapes of nitrogen results in different environmental negative impacts such as groundwater and soil acidification and eutrophication. Nitrogen compounds involve in ozone, oxidants and smog formation and are potentially harmful for human health (Bazrgar *et al.*, 2012).
For understanding the agro-ecosystems it is necessary to simplifying them. A useful way is quantifying system procedures in order to evaluate the system effectiveness. Thus it is necessary to quantify many qualitative aspects of agro-ecosystem while sustainability is a concept and is not measurable. Selecting proper indices is needed to evaluate the system sustainability. In fact each sustainability index is a numerical value gained by gathering different sustainability scales. Using sustainability indices is the first step in scheming a stable ecosystem. Such agro-ecosystems have low environmental impacts and stable social and economic efficiency while producing a proper crop yield (Mahdavi *et al.*, 2005). Various indices proposed for evaluating agro-ecosystem sustainability, but just a few of them are enough fast and simple in monitoring system. Researches show that proper sustainability indices are suitable for

evaluating system interferences with environment (Agol *et al.*, 2014). Nitrogen loss is a proper sustainability index.

Fertilizer managers, biologists, ecologists and environment scientist interest in evaluating nitrogen management and its environmental impacts (Delgado *et al.*, 2008).

Measuring nitrogen loss is difficult thus many simulating models developed to evaluate it (Van *et al.*, 2014).

SUNDIAL simulation model had used in many researches and its accuracy had approved (Bradbury *et al.*, 1993; Gabrielle *et al.*, 2002; Smith *et al.*, 2003; Gibbons *et al.*, 2005).

SUNDIAL had used by 250 researchers around the world (RRES, 2011). Tzilivakis *et al.*, (2005) applied the SUNDIAL to simulate nitrogen loss ad its environmental impacts at sugar beet fields.

Bazrgar *et al.*, (2012) used the model to evaluate nitrogen loss in sugar beet areas of Khorasan-Razavi-Iran.

Gibbons *et al.*, (2005) applied the model to improve fertilizer management and decrease nitrate loss among the fields. Fallon *et al.*, (1999) used the SUNDIAL model to simulate nitrogen cycle among the traditional faming systems.

The present study compared production sustainability of maize, barley and wheat base on nitrogen dynamics using SUNDIAL simulating model and provide proper ways for stable production.

MATERIALS AND METHODS

Neyshabur is located at 110 km of Mashhad south-west with a latitude between 35° 40′ and 36° 50 ′ E and a longitude between 58° 15 ′ and 59° 15 N ′ and 1230 m altitude.

The average temperature of Neyshabur is 15.5 °C with 253 mm yearly precipitation. A survey research performed during 2012-2013 growing season at rural regions around Neyshabur.

For maize, barley and wheat, 9, 15 and 13 fields chose randomly. All agronomic information of the fields inquired from famers and field managers by face to face interviews.

The field information presents at table 1. Collected data arranged using Excel software. SUNDIAL software applied to simulate nitrogen loss (Smith *et al.*, 1996).

Environmental impacts and nitrogen balance evaluate using N-loss model (Bazrgar *et al.*, 2012). Analysis of variance calculated using SAS. Comparison between means performed using LSD test if F-test was significant. Production sustainability of maize, barley and wheat evaluated using sustainability index, impact index and efficiency index (Scholefield and Smith, 1996; Fallon *et al.*, 1999; Smith *et al.*, 1998):

Sustainability Index (S.I.) = Total N input / (N removed in product + other losses)

Efficiency Index (ELI.) = N in product / N input as fertilizer Environmental

Impact Index (Env.I.) = Total N losses / N in product

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Table 1: Maize, barley and wheat filed management information in Neyshabur

Management	**Barley**					**Wheat**							**Maize**	
planted varieties	Bahman	Valfajr	Yousef	Abidar	Reyhan	Alvand	Sayons	Gascogen	Omid	Pishtaz	Falat	Farsian	Jovein	Moghan
Planting date	Oct 12^{th}	Oct 29^{th}	Nov 21^{th}	Dec 11^{th}	Dec 21^{th}	Oct 22^{th}	Oct 23^{th}		Oct 30^{th}		Nov 28^{th}	Nov 16^{th}	Apr 27^{th}	Jun 10^{th}
Harvesting date	Jun 10^{th}	Jun 18^{th}	Jun 12^{th}	Jun 7^{th}	Jun 17^{th}	Jul 4^{th}	Jun 22^{th}		Jun 23^{th}		Jun 18^{th}	Jun 26^{th}	Sep 16^{th}	Oct 20^{th}
Manure (ton/ha)	0					1.5							Max 11	
Ammonium phosphate (kg N/ha)	25.47					27							25.5	
Urea (kg N/ha)	24.53					32.87							46	
Time and rate of split application of nitrogen (kg N/ha) min	One time- 70.95					One time- 69							Three times- 69	
max	Three times- 33.07					Three times- 33.66							Twelve times-15.34	
Foliar fertilization kg N/ha	2.65					0.76							2.01	
Total N application (kg N/ha)	112.86					128.47							171.28	
Total water input (m^3/ ha)	500.2					651.8							1074.7	
Soil texture	Loam sandy					Loam							Loam, loam sandy, loam clay (with adequate amounts)	

RESULTS AND DISCUSSION

Nitrogen Loss per Unit of Harvested Area of Maize, Barley and Wheat

Analysis of variance of nitrogen dynamic simulation showed at table 2. The amount of nitrogen absorption by maize, barley and wheat was 181.2, 79.1 and 92.2 kg N/ha respectively.

Hu *et al.*, (2008) reported that maize could absorb 290 to 295 kg N/ ha and thus is proper nitrogen storage.

There was a significant difference between maize, barley and wheat in respect of total nitrogen loss ($p<0.01$) (table 2). The highest and lowest nitrogen loss belonged to maize (48.1 kg N/ha) and wheat (23.3 kg N/ha) respectively (figure 1).

Gaseous nitrogen loss was significantly different between studied crops ($p<0.01$) (table 2). Most of gaseous loss occurred through NH3 volatilization.

There was significant difference between crops in respect of volatilization rate (table 2). The highest volatilization amount belonged to maize (35.4 kg N/ha) (figure 1).

It seems that higher rate of fertilizer application in maize production resulted in higher nitrogen loss and volatilization rate per unit of harvested area in maize compare with barley and wheat. Denitrification rate was less in maize (3.3 kg N/ha) compare with barley (6.8 kg N/ha) and wheat (7.7 kg N/ha) but the difference was not significant (table 3).

The rate of denitrification was less than NH3 volatilization in the studied crops (figure 1). Soltani *et al.*, (2013) reported 0.09 to 1.44 kg N/ha gaseous loss of nitrogen in different studies.

Linear relation between nitrogen rate and NH3 vitalization presents at figure 2. There was significant correlation between nitrogen rate and NH3 volatilization (R2=0.79). Higher nitrogen fertilization application was more correlated with NH3 volatilization rather than denitrification.

Jones and Jacobsen (2005), Brentrup *et al.*, (2001) and Bazrgar *et al.*, (2012) reported that applying nitrogen fertilizers especially urea results in higher NH3 volatilization due to enhancing pH of soil. Mixing N-fertilizers with soil, splitting application of N-fertilizers in calm weather and enhancing top dressing times resulted in lower gaseous loss of nitrogen particularly NH3 volatilization (Soltani *et al.*, 2010; Bazrgar *et al.*, 2012).

Amount of nitrogen loss through leaching was 9.3, 4.1 and 2.3 kg N for maize, barley and wheat respectively (table 3).

This may be the result of filed management, amount of top dressed urea, irrigation method and amount and planting date. In barley and wheat long growing season resulted in higher nitrogen leaching. Gibbons *et al.*, (2005) reported that nitrogen leaching affected by planting date and planting method.

Applying lower amount of nitrogen fertilizer in irrigation water, foliar fertilization, and mechanized irrigation methods resulted in lower nitrogen leaching in wheat production while higher amount of top dressing urea, high amount of irrigation water, and applying higher amount of nitrogen in irrigation water resulted in higher leaching rate in maize production.

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Table 2: Source of variation, degree of freedom and mean of squares for measured traits

Source of variation	Degree of freedom	N absorption by plant	Gaseous N loss (denitrification and volatilization)	Total N loss	Leaching	Denitrification	NH3 volatilization	NO_x loss	NO_2 loss	NO_x loss/ 1000 kg of production	N_2O loss/ 1000 kg of production	Leaching loss/ 1000 kg of production	Gaseous loss/ 1000 kg of production	Total N loss/ 1000 kg of production
Treatment	2	32032.2**	662.854*	1401.90**	136.797**	56.434	1053.46**	0.101*	2.281*	0.0136**	0.28**	2.207	105.361**	136.393**
Error	34	1884.3	224.433	331.91	29.521	151.724	102.09	0.0299	0.674	0.00089	0.2232	1.811	18.499	27.505
Total	36	-	-	-	-	-	-	-	-	-	-	-	-	-

** and ** significant at 5 and 1 probability levels respectively*

Table 3: Comparison between means of measured traits

Treatment	N absorption by plant	Gaseous N loss (denitrification and volatilization)	Total N loss	Leaching	Denitrification	NH3 volatilization	NO_x loss	NO_2 loss	NO_x loss/ 1000 kg of production	N_2O loss/ 1000 kg of production	Leaching loss/ 1000 kg of production	Gaseous loss/ 1000 kg of production	Total N loss/ 1000 kg of production
Maize	181.22a	38.778a	48.111a	9.333a	3.33a	35.444a	0.479a	2.275a	0.0075b	0.038b	0.1588a	0.696	0.855b
Barley	79.067b	27.2ab	31.267b	4.066b	7.733a	19.467b	0.302b	1.44b	0.0719a	0.137a	1.0436a	6.577a	7.62a
Wheat	92.231b	/308b 23	25.615b	2.307b	6.769a	16.538b	0.3116b	1.478b	0.0696a	0.333a	0.674a	5.756a	6.4309a

There was no significant difference between means with the same letters in each column

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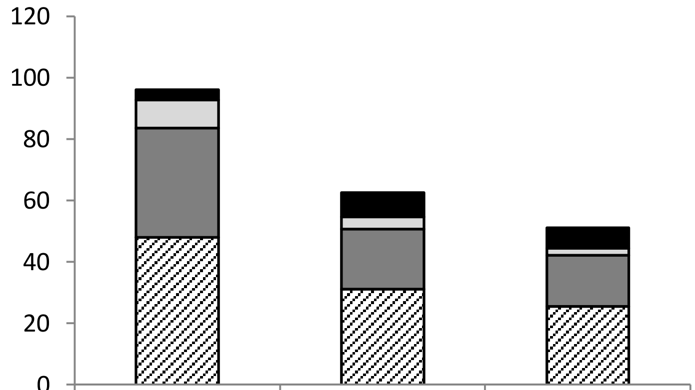

	maize	barley	wheat
■ Denitrification	3.33	7.733	6.769
□ Leaching	9.333	4.066	2.307
■ NH3 volatilization	35.444	19.467	16.538
▨ Total N loss	48.111	31.267	25.615

Figure 1: Comparison between maize, barley and wheat in respect of nitrogen loss per production area

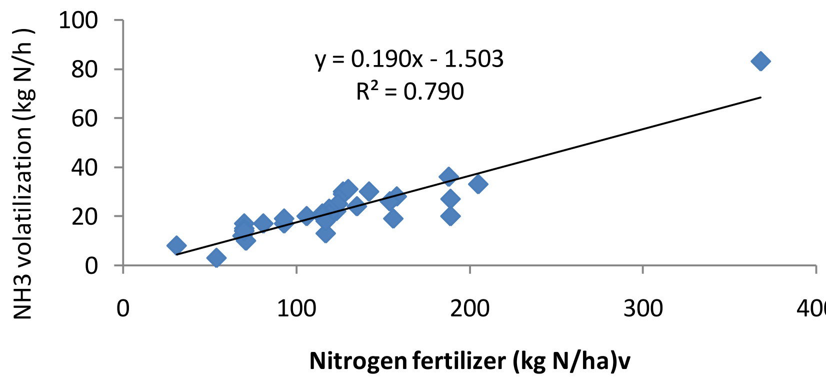

Figure 2: Relation between nitrogen application rate and NH3 volatilization in maize, barley and wheat

Nitrogen Loss per Production Unit of Maize, Barley and Wheat

Results showed that there was significant difference between production of 1000 kg of maize, barley and wheat in respect of gaseous loss. There was no significant difference between per production unit of studied crops in respect of leaching amount (table 2). Mean nitrogen loss through maize production was significantly less than barley and wheat. Nitrogen loss per 1000 kg production of maize, barley and wheat were 0.85, 7.6 and 6.4 kg respectively.

Nitrogen loss to air and water was 0.69 and 0.16 kg per 1000 kg of maize production. There was no significant difference between barley and wheat in respect of nitrogen loss to air and water (table 3). The amount of nitrogen loss to air was higher than those of water. Nitrogen loss per unit of area was higher in maize compare with barley and wheat.

But applying yield weight as scale showed that nitrogen loss was lower during 1000 kg production of maize rather than barley and wheat (figure 3). Thus all shapes of nitrogen loss were less during maize production compare with barley and wheat, in respect of yield production.

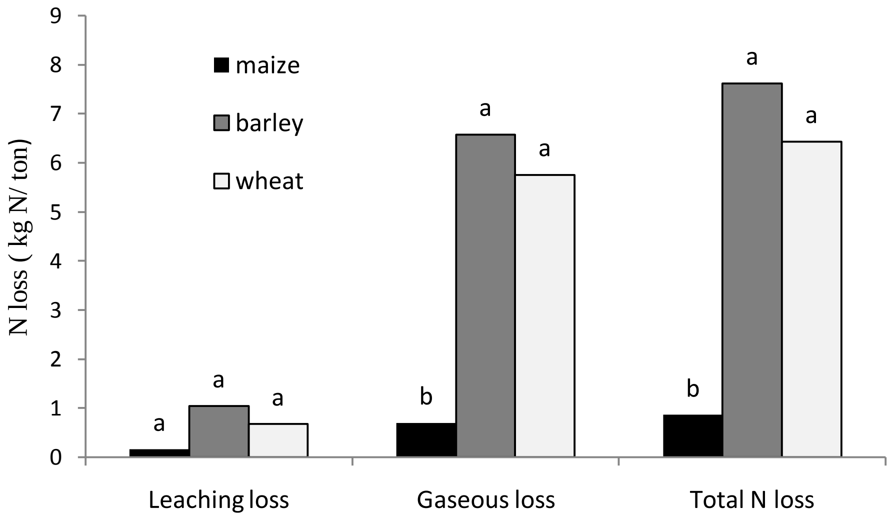

Figure 3: Comparison between maize, barley and wheat in respect of nitrogen loss per production unit

Nitrogen Greenhouse Gas Emission of Maize, Barley and Wheat

There was significant difference between maize, barley and wheat in respect of NO_2 and NO_x emission per harvested area ($p<0.05$) and per production unit ($p<0.01$) (table 2). 0.48, 0.3 and 0.32 kg N/ha nitrogen lost through NO_x formaize, barley and wheat respectively. 2.75, 1.4 and 1.48 kg N/ha lost as NO_2 for maize, barley and wheat respectively (table 3). 0.04, 0.31 and 0.33 kg nitrogen lost through NO_2 through production of each unit of maize, barley and wheat respectively. 0.007, 0.07 and 0.04 kg nitrogen lost as NO_x for each unit of maize, barley and wheat production respectively. NOx and NO2 loss was less in maize production compere with barley and wheat (figure 4).

The impact of NOx and NO2 emission of global warming is 310 folds more than CO2. Nemecek and Kagi (2007) reported that nitrogen loss through NO2 is related to agricultural nitrogen cycle and intensive agro-ecosystems results in higher NO2 emission.

Studied maize production systems in Neyshabur were intensive and resulted in high NO2 emission (figure 4).

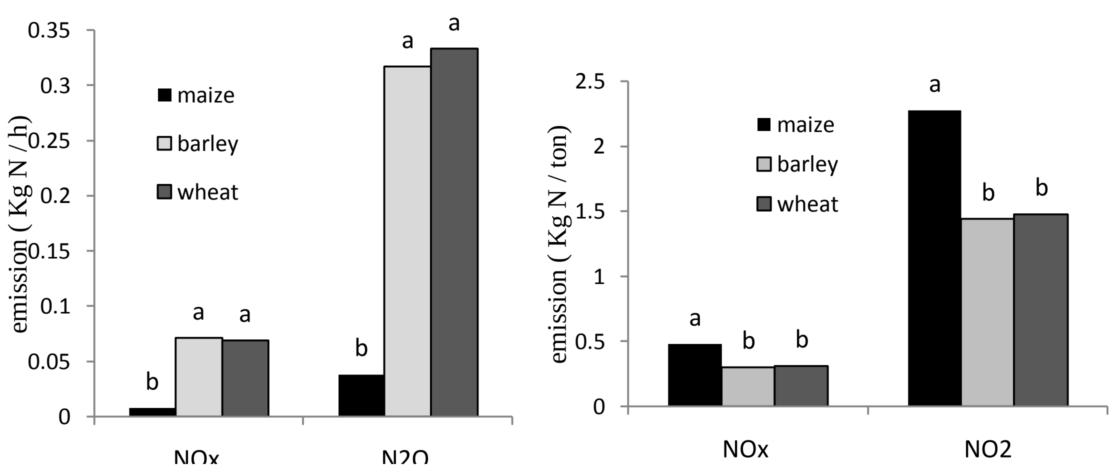

Figure 4: Nitrogen greenhouse gass emission during maize, barley and wheat production

Environmental Indices of Maize, Barley and Wheat

There was significant between maize, barley and wheat in respect of sustainability index and efficiency index. But there was no significant difference between them in respect of impact index (table 4). Sustainability index for maize (0.88) was significantly lower than barley (1.23) and wheat (1.21). but therewas no significant difference between barley and wheat in respect of sustainability index. Total nitrogen input was higher in maize production and nitrogen absorption and loss was higher in maize production too.

Table 4: Mean comparision of sustainability index, efficiency index and impact index in maize, barley and wheat

Treatment	Sustainability index	Efficiency index	Impact index
Maize	0.8865b	1.1153a	0.2693a
Barley	1.2306a	0.7748b	0.4233a
Wheat	1.21083a	0.8726ab	0.3416a

There was no significant difference between means with the same letters in each column

Table 5: Source of variation, degree of freedom and mean of squares for measured traits

Source of variation	Degree of freedom	Sustainability index	Efficiency index	Impact index
Treatment	2	0.38110*	0.32989*	0.06911ns
Error	34	0.11072	0.09332	0.08005
Total	36	-	-	-

** and ** significant at 5 and 1 probability levels respectively*

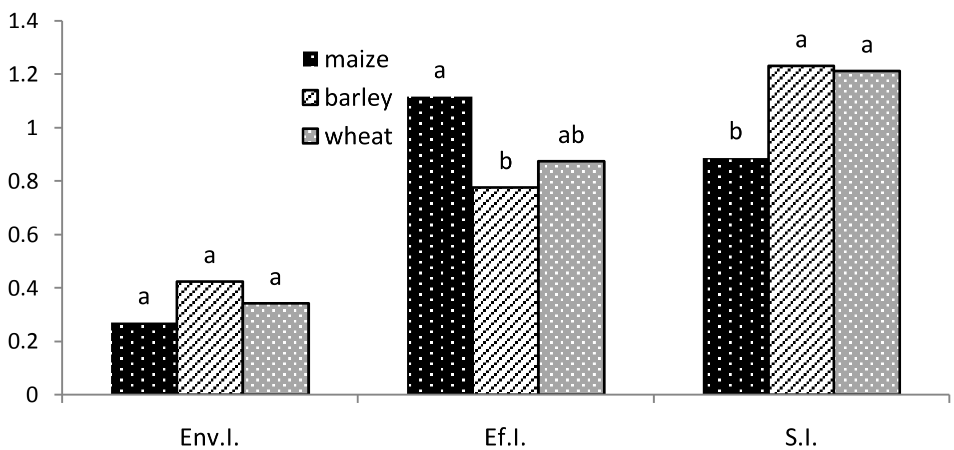

Figure 6: Sustainability, efficiency and impact indices in maize, balrey and wheat

Sustainability index lower than one shows unsustainability of agro-ecosystem. Base on the results maize production was an unsustainable agro-ecosystem in Neyshabur while barley and wheat productoin was stable. There was significant difference between maize and barley in respect of efficiency index.

Efficiency index of wheat was not significantly different whit maize and barley. Higher percent of total applied nitrogen abrobed by maize rather than barley and wheat, thus the efficieny indexwas higher for maize rather than two other crops. Thus maize production in Neyshabur had high efficieny in respect of nitrogen. Nitrogen application in barley and wheat washigher than crop need. There was no significant diffeence between studied crops in respect of impact index (figure 6). Impact index was 0.27, 0.42 and 0.34 for maize, balrey and wheat respectively. Impact index was higher for barley and wheat which showed higher destructive potential of these two agro-ecosystems in Neyshabur. Fallon *et al.,* (1999) reported that low input agro-ecosystems of maize with application of organic and inorganic fertilizers show high sustainability and low environment impact in Nepal.

Conclusion

Comparing the results of SUNDIAL simulating model with the results of other researches showed that SUNDIAL was approprite in simulating nitrogen loss through crop production in Neyshabur. The highest nitrogen loss in maize (73%), barley (64%) and wheat (62%) occurred through NH3 volatilization. The second nitrogen loss factor was leaching in maize (19%) and denitrification in barley (25%) and wheat (26%). The third nitrogen loss factor in barley and wheat was leaching with 13 and 9% of total nitrogen loss respectively. Thus it is important to manage nitrogen application in maize, barley and wheat. Applying fertilizers with lower gaseous emission potential, applying accurate top dressing methods (blend the fertilizer with soil), select the proper time and environmental conditions for applying N-fertilizer (low temperature and calm weather) are some managing instructions for better nitrogen application. Results showed that 2.75 and 0.48 kg N/ha of NOx and NO2 produced per 1000 kg of maize production. Each unit of maize production released 0.03 and 0.0007 kg N as greenhouse gas to the air. There was significant difference between maize, barley and wheat in respect of total nitrogen loss and nitrogen loss to air. But there was no significant difference between studied crops in respect of nitrogen loss to water. Total nitrogen loss and nitrogen loss to air was lower than barley and with due to higher yield of maize compare with barley and wheat. Investigating environmental impact indices showed that barley and wheat production is sustainable in respect of soil nitrogen, but these agro-ecosystems showed low efficiency and high environment impact.

Suggestions

Nitrogen loss is not limited to field production. A high amount of nitrogen loss occurs after harvest and during production procedure. Evaluating after harvest nitrogen loss is recommended for future studies. No environmental standards suggested for Iran agro-ecosystems. Thus it is necessary to investigate managing methods for all crops in each location and preparing environmental standards for each crop.

REFERENCES

Agol D, Latawiec AE and Strassburg BN (2014). Evaluating impacts of development and conservation projects using sustainability indicators: Opportunities and challenges. *Environmental Impact Assessment Review* **48** 1-9.

Bazrgar AB, Soltani A, koocheki A, Zeinali E and Ghaemi A (2012). *Environmental Assessment of Khorassan Sugar Beet Production Systems using LCA, PhD Dissertation*. Gorgan university of Agricultural and Natural resources (GUASNR Press).

Bradbury NJ, Whitmore AP, Hart PBS and Jenkinson DS (1993). Modeling the fate of nitrogen in crop and soil in the years following application of 15N-labelled fertilizer to winter wheat. *Journal of Agricultural Science* **121** 363 -379.

Brentrup F, Sters JKU, Kuhlmann H and Lammel J (2001). Application of the Life Cycle Assessment methodology to agricultural production: an example of sugar beet production with different forms of nitrogen fertilizers. *European Journal of Agronomy* **14** 221–233.

Delgado JA, Shaffer M, Hu C, LavadoR, Cueto-Wong J, Joosse P, Sotomayor D, Colon W, Follett R, DelGrosso, S, LiX and Rimski-Korsakov H (2008). An index approach to assess nitrogen losses to the Environment. *Ecological Engineering* **32** 108–120.

Essiet EU (2001). Agricultural sustainability under small-holder farming in Kano, northern Nigeria. *Journal of Arid Environments* **48** 1-7.

Falloon P, Pilbeam C and Smith J (1999). Modeling nitrogen cycling in the arable systems of Nepal using SUNDIAL. IACR-Rothamsted Technical Report, University of Reading, Whiteknights, Reading, UK.

Gabrielle B, Mary B, Roche R, SmithP and Gosse G (2002). Simulation of carbon and nitrogen dynamics in arable soils: a comparison of approaches. *European Journal of Agronomy* **18** 107-120.

Galloway JN, Townsend AR, Erisman JW, Bekunda M, Cai Z, Freney JF, Martinelli LA, Seitzinger SP and Sutton MA (2008). Transformation of the nitrogen cycle: recent trends, questions, and potential solutions. *Science* **320** 889–892.

Gibbons JM, Sparkes DL, Wilson PL and Ramsden SJ (2005). Modelling optimal -strategies for decreasing nitrate loss with variation in weather – a farm-level approach. *Agricultural Systems* **83** 113–134.

Hu K, Li B, Chen D, Zhang Y and Edis R (2008). Simulation of nitrate leaching under irrigated maize on sandy soil in desert oasis in Inner Mongolia, China. *Agricultural Water Management* **95** 1180 1188.

Jones C and Jacobsen J (2005). Nitrogen Cycling, Testing and Fertilizer Recommendations, Nutrient Management Module No. 3. Extension Service, Montana State University, USA.

Nemecek T and Kagi T (2007). Life Cycle Inventories of Swiss and European Agricultural Production Systems. Final report ecoinvent **2**(15a). AgroscopeReckenholz- Taenikon Research Station ART, Swiss Centre for Life Cycle Inventories, Zurich and Dubendorf, CH.

Mahdavi Damghani A, Koochaki A, Rezvani Moghadam P and Nasiri Mahalati M (2005). Assorting a sustainability index in order to investigate wheat-cotton agro-ecosystem stability in Khorasan province. *Iranian Journal of Agricultural Science* **5** 129-142 [in Persian with English summary].

Rothamsted Research Institute (2011). Sundial: The Research Tool, available in:- http://www.rothamsted.bbsrc.ac.uk/aen/sundial/tool.htm.

Scholefield D and Smith JU (1996). Nitrogen flows in ley-arable systems. Legumes in Sustainable Fanning Systems, Craibstone.

Smith J, Scholefield D, Glendining M and Stockdale E (1998). Using models to optimise the efficiency of nitrogen across whole farm rotations. In: *Proceedings of an International Workshop on mixed farming systems in Europe*, edited by Keulen H Van, Lantinga EA and Vanlaar H, Dronten/Wageningen, The Netherlands 25-28 May 1998, Ir. A.P. Minderhoudhoeve-series no. 2.

Smith JU, Bradbury NJ and Addiscott TM (1996). Sundial: a PC-based system for simulating nitrogen dynamics in arable land. *Agronomy Journal* **88** 38–43.

Smith JU, Smith P, Richter GM, Agostini FA and Welham SJ (2003). Testing the adequacy of measured data for evaluating nitrogen turnover models by the dot-to-dot method. *European Journal of Soil Science* **54** 175–185.

Soltani A, Rajabi MH, Zeinali E and Soltani E (2010). Evaluation of environmental impact of crop production using LCA: wheat in Gorgan, *EJCP* **3**(3) 201-218

Soltani E, Soltani A, Zinali A and Dastmalchi A (2013). Simulating wheat nitrogen loss using cropSyst in Gorgan. *Journal of Water and Soil Preservation* **20**(4) 145-163 [in Persian with English summary].

Tzilivakis J, Jaggard K, Lewis KA, May M and Warner DJ (2005). Environmental impact and economic assessment for UK sugar beet production systems. *Agriculture, Ecosystems and Environment* **107** 341–358.

Van der Laana M, Annandalea JG, Bristowa KL, Stirzakera RJ, du Preezc CC, Thorburnb PJ (2014). Modeling nitrogen leaching: Are we getting the right answer for the right reason?. *Agricultural Water Management* 74–80.

