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LIFE CYCLE ASSESSMENT OF NPK FERTILIZERS IN RICE PRODUCTION IN NORTHERN IRAN

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ABSTRACT

Life cycle assessment is an appropriate method to study the environmental impacts of producing a crop product throughout its cycle in a production system. Therefore, this research was conducted with the aim of evaluating the life cycle of paddy rice production under the effects of NPK fertilizers in Mazandaran province in northern Iran during 2017-2018. The different doses of nitrogen (N), phosphorus (P) and potassium (K) fertilizers were $N_{250}P_{150}K_{150}$, $N_{200}P_{100}K_{100}$, $N_{150}P_{75}K_{75}$, $N_{100}P_{50}K_{50}$, and control ($N_0P_0K_0$). The results displayed that an average amount of cumulative energy demand and cumulative exergy demand was 11549.78 and 13443.08 MJ, respectively, that with increase of NPK consumption, both indices showed increasing trend. The average ecological footprint was 1190.80 m^2 a which CO_2 emissions had shown the highest effect on the ecological footprint. The average of the impact categories of abiotic depletion was equals 12.44 kg Sb eq, acidification (3.15 kg SO_2 eq), eutrophiction (2.33 kg PO_4 eq), malodorous air (7295733 m^3 air), freshwater sediment ecotoxicity (75.79 kg 1.4 DB eq), marine sediment ecotoxicity (116.11 kg 1.4 DB eq) that all of which enhanced with increasing NPK consumption. The average global warming potential (GWP) 20a and GWP 500a were 399.20 and 382.97 kg CO_2 eq, respectively. Two indicators of human toxicity and terrestrial ecotoxicity in the three periods of 20, 100 and 500 years shows increasing amounts equal 0.42% and 140.70% during 20a to 500a, respectively. All pollutants released into the air and the water demonstrated enhancing trend with increasing NPK amounts. The emission of nitrate into soil, metals into the soil, and chemical oxygen demand showed enhancing trend with increasing NPK levels. Therefore, enhancing the emission of pollutants by increasing nitrogen consumption can be due to increase of yield.

Keywords: cumulative exergy demand, ecological footprint, eutrophication, global warming potential, heavy metal emission.

INTRODUCTION

Rice (*Oryza sativa* L.) is the earliest stable food crops with the global cultivation area of 165 million hectares, accounting for more than one tenth of the worldwide-cultivated area (FAOSTAT, 2018). According to the report published in 2018, in Iran, the paddy field cultivation area is about 630,000 million hectares, from which a product with a volume of 2.5 million tons is obtained (Ministry of Jihad-e-Agriculture of Iran, 2021). Mazandaran province in northern Iran is the largest rice producing area in Iran with 230,000 ha cultivation area, accounting for 38% of the total rice cultivation and production area in Iran (Ministry of Jihad-e-Agriculture of Iran, 2021). Therefore, Mazandaran province have a high share of rice production area in Iran, which requires optimization of inputs application and identification of the best production system in order to reduce the emission of environmental pollutant.

Life cycle assessment (LCA) is an appropriate way for achieving sustainable agriculture goals to study the environmental impact of a crop producing in its whole life cycle in production systems (Dastan et al., 2019). LCA used in crop planting systems is an attempt to estimate all GHGs emission and environmental pollutants of the production chain of life cycle (Goossense et al., 2017). Several studies have been found in this regard. Dastan et al. (2019) by using LCA

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assessed transgenic Bt. and non-Bt. rice cultivars in northern Iran. They reported that the amount of the environmental pollutants emission is directly related to the application of inputs and method of field management, based on which the least amounts of these indices were obtained in the production of transgenic cultivars. Habibi et al. (2019) by using LCA to assess 200 rice production fields in Mazandaran and Guilan provinces, Iran reported that the most global warming potential (GWP 100a), climate change (CC) and cumulative energy demand (CED) in both regions were observed in high-input system for semi-mechanized method. The result for the impact categories of freshwater eutrophication (FE), agricultural land occupation (ALO), terrestrial acidification (TA), marine eutrophication (ME), metal depletion (MD), fossil depletion (FD) and water depletion (WD) was similar to the GWP, CC and CED where the highest amounts in both regions statistically went to high-input system. They reported that in both regions, high-input and conventional systems emitted higher heavy metals than low-input system (Habibi et al., 2019). Using LCA, Siavoshi and Dastan (2019) assessed environmental impact of nitrogen fertilizer on wheat production in Boushehr region, southern Iran. They reported that CED, cumulative exergy demand (CExD), ecological footprint (EF), abiotic depletion (AD), acidification, eutrophiction, malodorous air (MA), freshwater sediment ecotoxicity (FEW), marine sediment ecotoxicity (MSE), GWP 20a, GWP 500a, human toxicity (HT) and terrestrial ecotoxicity (TE) in the three periods of 20, 100 and 500 years enhanced with increasing nitrogen consumption. Using LCA, Siavoshi and Dastan (2021) assessed 200 wheat fields were identified which 100 farms belonging to rainfed cultivation in Genaveh region and 100 farms belonging to irrigated cultivation in Dashty region, Boushehr province in southern Iran were monitored. They reported that CED, CExD, greenhouse gas protocol (GGP), IPCC 2013 GWP 100a, EF and water footprint (WF) in rainfed cultivation were significantly higher than irrigated cultivation. The impact category indices associated with the CML-IA non-baseline model, such as GWP 500a, acidification, eutrophication, ionising radiation, MA, OLD 40a, HT 100a, freshwater and MAE 100a in rainfed cultivation were significantly higher than irrigated cultivation. Impact category of heavy metals emitted into air (Pb, Cd, Zn and Hg), heavy metals emitted into water (Cr, Zn, Cu, Cd, Hg, Pb and Ni), nitrate into soil, metals into soil, pesticide into soil, and emission of NOx, SOx, NH_3, dust, COD, phosphorous and nitrogen in the rainfed method was much higher than irrigated cultivation (Siavoshi and Dastan, 2021). Using LCA, Ebrahimi et al. (2018) assessed environmental impact of irrigation regimes with application of nano silicon and nano potassium in wheat production in southern Iran. They displayed that carbon dioxide emission increased by two-day irrigation intervals about 5.47 percent compared to the eight-day irrigation interval, but the land occupation increased about 7.2 percent. With increasing irrigation intervals from two days to eight days, the impact categories of ecosystem quality, resource depletion, agricultural water scarcity, water depletion index (WDI) and water scarcity index (WSI) were decreased about 8.21, 8, 10.89, 9.29 and 9.91 percent. With the consumption of nano-silicon and nano-potassium chelate, the resource depletion, agricultural water depletion, WDI and WSI were lower than control treatment. The WDI about 7.28% and 8.24%, and about 9.7% and 8.57% was decreased with consumption of nano-silicon and nano-potassium chelate compared to control. Using LCA, He et al. (2018) showed that organic rice production system had lower environmental impact compared to conventional system in sub-tropical China throughout the life cycle. They announced that chemical fertilizer and pesticide utilization were the main factors causing higher non-renewable energy depletion, GWP, FE, TA, WD, soil toxicity, human toxicity potential, land occupation and aquatic toxicity potential in organic rice production system.

The scientific literature reviewing showed that it is of great necessity to assess the life-cycle of NPK fertilizers in paddy fields to determine emissions of environmental pollutant. To the best of our knowledge, LCA has not been applied to specifically assess the environmental impact of rice cultivars in different NPK fertilizers in Iran. Hence, the findings of this study can be very effective in increasing the rice ecosystem's sustainability, as well as reducing the environmental impacts resulting from the application of chemical inputs and the achievement of sustainable agricultural objectives.

MATERIAL AND METHODS

Description of the experimental site and the region

Field experiments were conducted in Sari region (in the central part of Mazandaran province), located in north of Iran between the Alborz Mountains and the Caspian Sea during the periods of 2017 and 2018. The experimental region is geographically situated at 36°38' N latitude and 53°12' E longitude. According to the climatic parameters, and topography of the region, Mazandaran province is divided into two climates which included Caspian humid weather and mountain mild weather (Habibi et al., 2019). This research covers Caspian humid climates. Harvest period of rice in the north of Iran is usually during September, after which clover, canola or wheat is sown in a double cropping system (Habibi et al., 2019).

Description of the experiment

The experiment was conducted as split plots based on a randomized complete blocks design (RCBD) with four replications. The different doses of nitrogen (N), phosphorus (P) and potassium (K) fertilizers were $N_{250}P_{150}K_{150}$; $N_{200}P_{100}K_{100}$; $N_{150}P_{75}K_{75}$; $N_{100}P_{50}K_{50}$, and control ($N_0P_0K_0$).

Description of the field practices

Nursery preparation was done in the first and second year on April 10-12 and on April 13-14, respectively. To prevent nitrogen leaching and weed growth in paddy fields, nylon plastic cover was put at the borders to the depth of 30 centimeters of each plot. The size of main plots was 12×5 m^2 and the size of sub plots was 3×5 m^2.

Considering the regional climates, 'Tarom Hashemi' cultivar was transplanted. Seedlings were prepared by the traditional method (furrow and basin); transplanting (spacing of 20×20 cm^2 equals 25 seedlings per m^2) was done by two young seedlings per hill with 3-4 leaves (25 days old). Transplanting was done during the first and second years on May 24-25 and on May 27-28, respectively. Flooding + interval irrigation was done with two steps drainage during the maximum of tillering (initial heading stage) and full heading stage in the period of growing season. The depth of irrigation water was set at five centimeters according to agricultural principles of rice farming.

Chemical fertilizers were used in each plot according to the suggestion of Rice Research Institute of Iran (RRII) and by considering the result of soil analysis. Chemical fertilizers were used from urea sources (150 kg ha^{-1}) for nitrogen; followed by using the triple super phosphate according to treatment for phosphorus; and potassium sulfate (100 kg ha^{-1}) for potassium. Total phosphorus fertilizer containing 50% of the nitrogen and 50% of the potassium fertilizers was used as basal application in the paddy field preparation stage. In addition, 25% of the nitrogen and 25% of potassium fertilizers were used as top-dressing in panicle initiation stage. In addition, 25% of nitrogen was applied in full heading stage. To control weed, weedicide was applied once pre-emergence and, hand weeding was done at third steps (28, 40 and 50 days after transplanting). Pesticides were used to control the pests and diseases. Crop protection practices, such as irrigation, weeding, pests and diseases control, and fertilization, were done in the experiment paddy field based on technical instruction of RRII. Other agricultural practices and field management were done according to the Standard Evaluation System (SES) of the International Rice Research Institute (IRRI).

LCA methodology

"LCA is a technique to assess environmental impacts associated with all the stages of a product's life from raw material extraction through materials processing, manufacture, use, and disposal or recycling" (ISO 2006), and transportation. LCA is carried out in four main phases: definition of goals and scope; analysis of inventory; impact assessment; interpretation (Habibi et al., 2019). In this regard, four phases which are goal and scope definition, inventory analysis, impact assessment, and interpretation, were designed to assess life cycle index (Habibi et al., 2019).

Goal and scope

This LCA study aimed to evaluate and compare the environmental impact of producing local rice cultivar for NPK fertilizers. The functional unit was one ton of paddy yield (with 12% moisture content). Since straw is a co-product of paddy farms, economic allocation and environmental impact was assessed by the LCA method of SimaPro8.2.3 software (SimaPro, 2011). Based on economic allocation, about 90% and 10% of dry matter of experimental farms were attributed to paddy and straw, respectively (Soltani et al., 2013).

Life Cycle Inventory (LCI)

In this step, all emissions due to the production of inputs (indirect emission) and application of inputs (direct emission) in local and improved rice cultivars for cover crop-rice rotations produced were calculated using the Ecoinvent 3.1 database (www.pre-sustainability.com/news/ecoinvent-different-system-models). Items that were considered are: (i) infrastructures, comprising construction, maintenance and depreciation of machinery and buildings (shelters for machinery); (ii) all agricultural practices including bed preparation for cultivation, fertilization, protection, irrigation, harvest, transportation supply and utilization of fuel for the practices; (iii) production of fertilizers, herbicide and fungicide; and (iv) transportation of all inputs.

Life cycle impact assessment (LCIA)

"LCIA aims to evaluate environmental impacts based on inventory analysis within a framework of the goal and scope of the study. In this phase, the inventory results are assigned to different impact categories" (Roy et al., 2009). To do more comprehensive and accurate environmental impact assessment, which involves characterizing, normalizing and weighing, in the production of local rice cultivar in different amount of NPK fertilizers, different methods including Ecopoints 97 CH, cumulative energy demand (CED), greenhouse gas protocol (GGP), cumulative energy demand (CExD), IPCC 2013 GWP 100a, and CML non-baseline were used in SimaPro8.2.3 software (SimaPro, 2011). Characterization, which is the first step of LCIA, is the assessment of environmental impacts of each inventory flow "[e.g., modeling the potential impact of carbon dioxide (CO_2) and methane (CH_4) on global warming], and provides the ability to compare LCI results within each category" (Roy et al., 2009). For instance, CO_2, nitrous oxide (N_2O) and CH_4 have different environmental impacts on global warming. The GWP of CO_2, N_2O and CH_4 are 1, 265 and 28 kg CO_2 eq, respectively (IPCC, 2013). There are different classifications for impact categories depending on the method used. The most important impact categories in this study were GWP, TA, FE, ME, WD, CED and CExD. To conduct a deeper analysis, the amount of NH_3, N_2O and CH_4 emissions and heavy metals and other materials emitted in the air (Pb, Cd, Zn, Hg), water (Cr, Zn, Cu, Cd, Hg, Pb, Ni) and soil (nitrate, metals and pesticide) are reported separately in the results section. For each impact category, corresponding characterization factors were used based on the IPCC 2013 GWP 100a, Ecopoints 97 CH, CED and CExD methods in SimaPro8.2.3 software (SimaPro, 2011).

Interpretation

One of the aims of LCA is to provide comprehensive information for decision makers. To achieve this goal, LCA results of a study must be interpreted. In this step, the LCA results of NPK fertilizers for local ('Tarom Hashemi') rice cultivars were assessed and compared.

RESULTS AND DISCUSSION

Cumulative energy demand (CED) method

Cumulative energy demand (CED) model includes six indicators of non-renewable energy (fossil, nuclear and biomass) and renewable energy (biomass, water and wind-solar-geothermal) categories that all inputs on the farm (seeds, fuel, electricity, tools and machinery, nitrogen, phosphorus, potassium, and pesticides), all of which were considered as CED. According to the findings of Figure 1, the average amount of CED was 11549.78 MJ, with the largest share belonging to fossil fuels, machinery and nitrogen. With the increase in application of NPK fertilizers, the CED showed an increasing trend. $N_{250}P_{150}K_{150}$ had the highest CED (12729.79 MJ) and $N_0P_0K_0$ had the lowest CED (90335.90 MJ). According to the findings, all farm inputs and outputs (grain yield) affected cumulative energy demand. Therefore, enhance in CED with increasing NPK can be due to smaller changes in output (performance) and increased performance. This issue is of great ecological importance because the source of non-renewable energy, which is mainly fossil fuels, and relying on these sources in the future is associated with many risks.

Cumulative exergy demand (CExD) method

Cumulative Exergy Index (CExI) is the sum of all the resources needed to produce a product or provide a service. This index is similar to the more common index, CED, except that CED measures the quality of energy sources as well as non-energy sources such as minerals and metals (Siavoshi and Dastan, 2019). This method includes 10 indices of non-renewable energy (fossil, nuclear, metals and minerals) and renewable energy (kinetic, solar, potential, primary energy, biomass and water), all of which were considered as CExD. According to the findings in Figure 1, all farm inputs affected on this index.

The average of this index with consumption of different amounts of NPK was 13443.08 MJ, which was 16.39% higher compared to the CED. Cumulative exergy demand with increasing NPK consumption, showed a increasing trend from 12079.50 MJ to 14741.56 MJ (Figure 1). According to the findings, all inputs and outputs had an effect on cumulative exergy demand that the share of fossil fuels, seeds consumed, machinery and nitrogen was higher than other inputs (inputs).

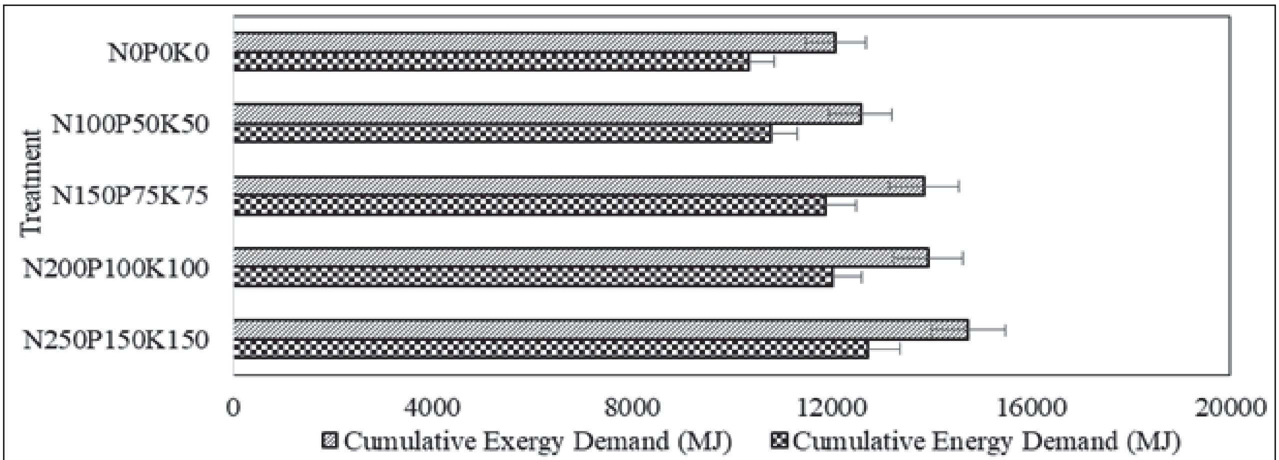

Figure 1. Effect of NPK on cumulative energy demand (CED) and cumulative exergy demand (CExD) in rice production

Ecological footprint (EF) method

In this method, the three impact categories of carbon dioxide, nuclear energy and land occupation based on square meters per year (m^2a) were evaluated. All inputs had an impact on the EF, with seeds, fossil fuels, nitrogen and machinery having the greatest impact on the EF (Figure 2). The average EF was 1190.80 m^2a, the share of carbon dioxide, nuclear energy and land occupation were 775.22, 73.55 and 342.03 m^2a, respectively. With increasing NPK consumption, the ecological footprint showed an decreasing trend (Figure 2). According to the findings, it can be seen that the carbon dioxide emission index has the highest effect on the ecological footprint and the land occupancy and nuclear energy indices are in the next ranks, respectively.

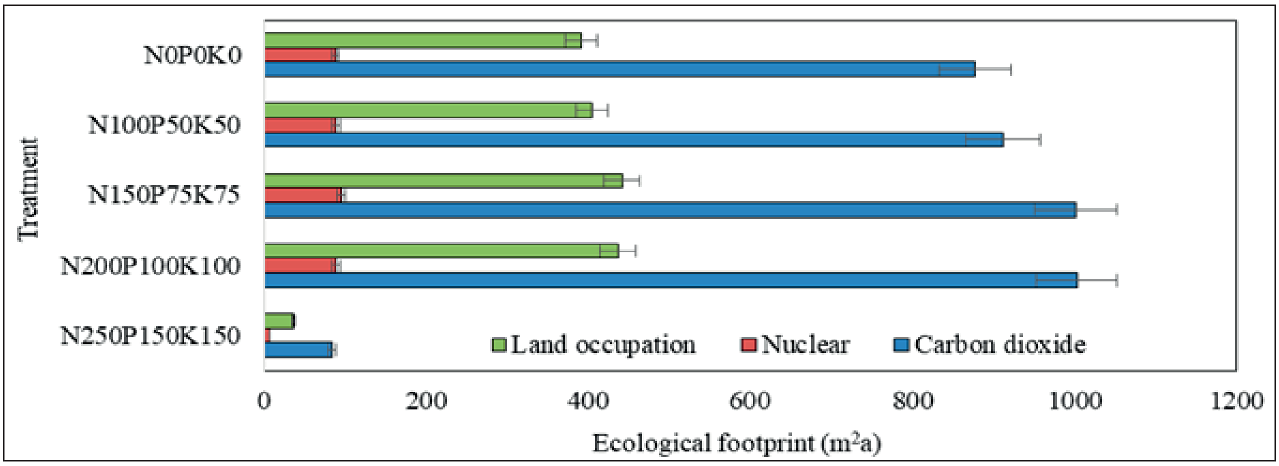

Figure 2. Effect of NPK fertilizers on impact categories of ecological footprint in rice production

CML non-baseline method

The values of the effect class indices related to the CML-IA non-baseline model are presented in Table 1 and Figures 3-6. In Table 1, the indices of abiotic depletion (elem.), land competition, acidification, eutrophication, ionizing radiation and malodorous air were evaluated. The average of impact category of abiotic depletion was equals 12.44 Sb, land competition (208.23 m^2a), acidification (3.15 kg SO_2 eq), eutrophication (2.33 kg PO_4 eq) and malodorous air (7295733 m^3 air), all of which increased with increasing NPK consumption. Enhancing the amounts of these impact categories with increasing NPK consumption shows that the output share (production performance) is higher than the NPK input share and showed a higher effect (Table 1). Mean amount of photochemical oxidation (low NOx and high NOx) were 0.0327 and 0.0529 kg C_2H_4 eq, respectively), freshwater sediment ecotox. 100a (75.79 kg 1,4-DB eq) and marine sediment ecotox. 100a (116.11 kg 1,4-DB eq) was obtained. Photochemical oxidation, marine sediment ecotox. 100a decreased with increasing NPK fertilizers, but freshwater sediment ecotox. 100a increasing amounts of elements showed an increasing trend (Table 1).

Table 1. Life cycle assessment of rice production under NPK fertilizers by CML-IA non-baseline model

Impact categories	Unit	$N_{250}P_{150}K_{150}$	$N_{200}P_{100}K_{100}$	$N_{150}P_{75}K_{75}$	$N_{100}P_{50}K_{50}$	$N_0P_0K_0$	Mean	SE	CV (%)
Abiotic depletion (elem.)	kg Sb eq	14.21	13.10	12.69	11.40	10.81	12.44	0.4950	9.74
Land competition	m^2a	218.39	212.73	216.97	199.40	193.65	208.23	4.04	4.75
Freshwater aquatic ecotox. 100a	kg 1,4-DB eq	58.03	70.28	83.95	82.11	84.59	75.79	4.20	13.57
Marine sediment ecotox. 100a	kg 1,4-DB eq	130.86	121.65	118.87	107.15	102.00	116.11	4.22	8.91
Photochemical oxidation (low NOx)	kg C_2H_4 eq	0.035	0.0338	0.0338	0.0309	0.0298	0.0327	0.0008	6.35
Photochemical oxidation (very high NOx)	kg C_2H_4 eq	0.0462	0.0471	0.0500	0.0467	0.0461	0.0472	0.0006	3.02
Photochemical oxidation (high NOx)	kg C_2H_4 eq	0.0534	0.0534	0.0556	0.0516	0.0506	0.0529	0.0007	3.25
Acidification	kg SO_2 eq	3.46	3.27	3.24	2.95	2.8271	3.15	0.0940	7.31
Eutrophication	kg PO_4--- eq	2.53	2.41	2.41	2.20	2.12	2.33	0.0619	6.50
Malodorous air	m^3 air	7548936	7419260	7625739	7032199	6852534	7295733	123037	4.13

The impact category of ozone layer depletion (OLD) for the period of 5 to 40 years (5a, 10a, 15a, 20a, 25a, 30a and 40a) are presented in Figure 3, with an average of 0.00015 kg CFC-11 eq. In all periods, the highest value of this impact category belonged to $N_{250}P_{150}K_{150}$ and the lowest value belonged to $N_0P_0K_0$. With increasing NPK consumption, this index showed a enhancing trend. These results show that optimal management of NPK consumption leads to the reduction of pollutants, including OLD. In addition, with increasing the time period from 5 to 40 years, the value of this index showed a decreasing trend (Figure 3).

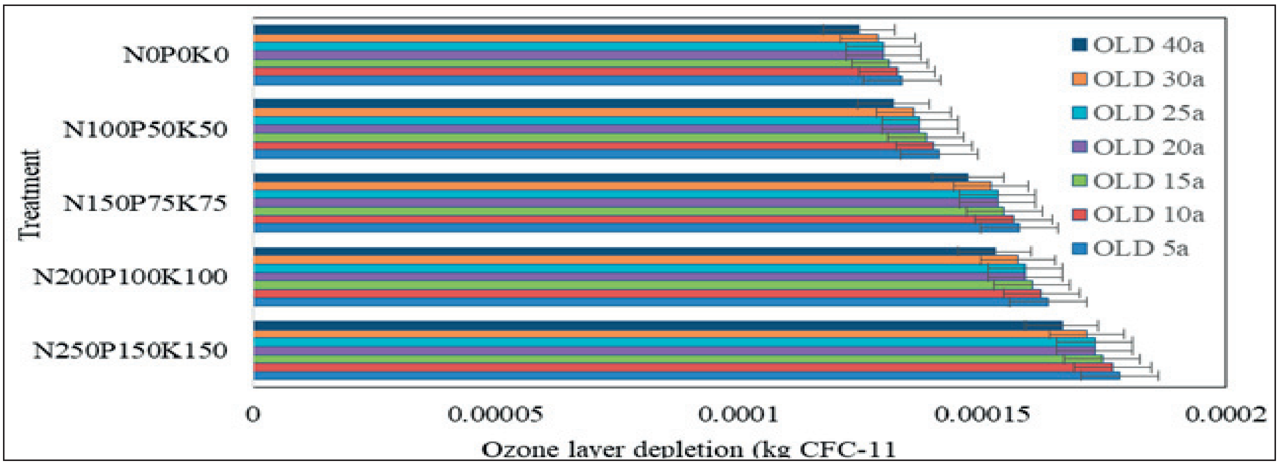

Figure 3. Effect of NPK fertilizers on impact categories of ozone layer depletion (OLD) during 5 to 40 years in rice production

The impact category of global warming potential (GWP) 20a and GWP 500a are presented in Figure 4. According to the findings, the average GWP 20a and GWP 500a was equal to 399.21 and 382.97 kg CO_2 eq. which decreased 4.07% from 20a to 500a. GWP during both periods (20a and GWP 500a) showed a variable trend, the highest of which was in $N_{250}P_{150}K_{150}$ (432.81 and 415.75 kg CO_2 eq, respectively) and the lowest was $N_0P_0K_0$ (361.97 and 346.90 kg CO_2 eq) (Figure 4).

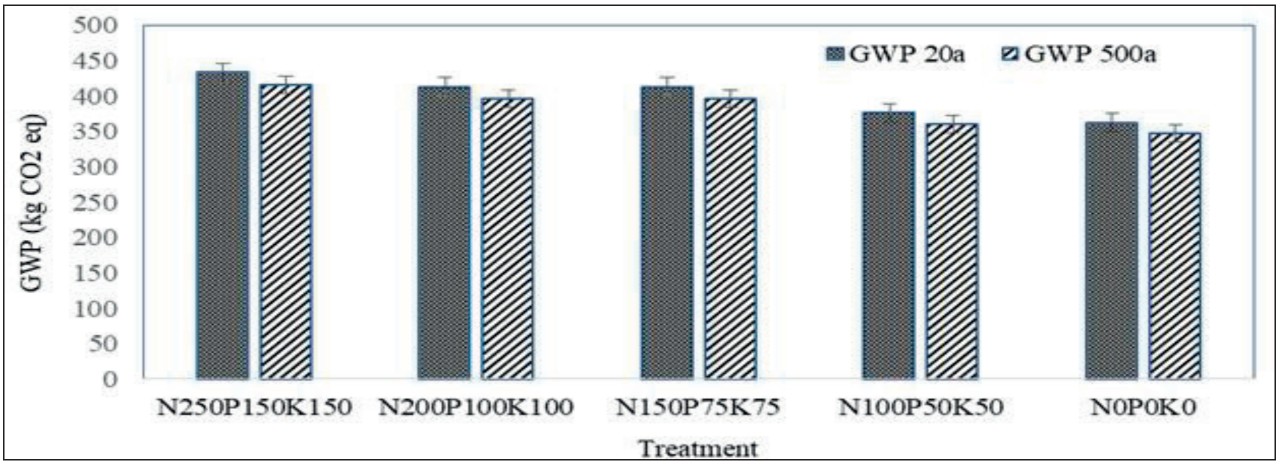

Figure 4. Effect of NPK fertilizers on global warming potential (GWP) during 20 to 500 years in rice production

Impact categories of human toxicity and terrestrial ecotoxicity during three periods (20a, 100a and 500a) are presented in Figures 5 and 6. Both impact categories increased by 0.42% and 14.70% with increasing time from 20 to 500 years. The average of impact category of human toxicity during 20a, 100a and 500a is equal to 359.91, 360.228 and 361.43 kg

1.4 DB eq) (Figure 5), and the impact category of terrestrial ecotoxicity during 20a, 100a and 500a were 7.28, 7.51 and 8.35 kg 1.4 DB eq, respectively (Figure 6).

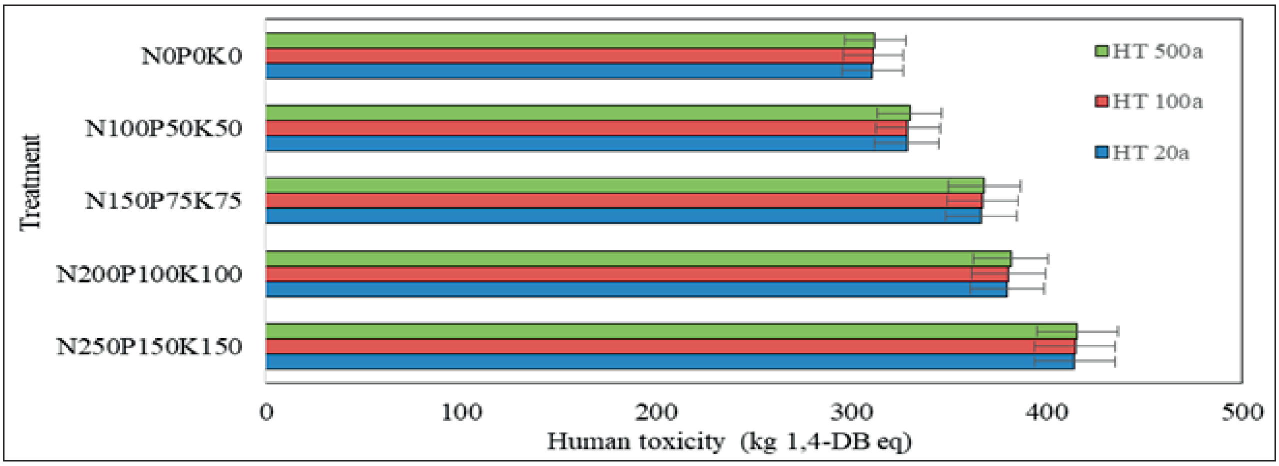

Figure 5. Effect of NPK fertilizers on impact categories of human toxicity (HT) during 20, 100 and 500 years in rice production

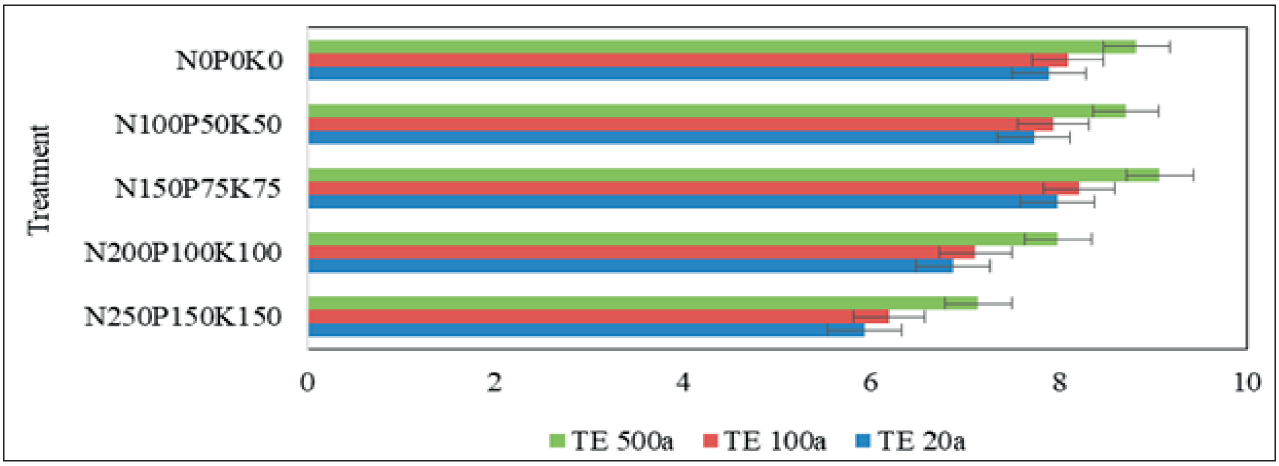

Figure 6. Effect of NPK fertilizers on impact categories of terrestrial ecotoxicity (TE) during 20, 100 and 500 years in rice production

Ecopoints 97 (CH) method

The findings in Table 2, which are derived from the Ecopoints 97 method with impact categories related to the emission of heavy metals and other environmental pollutants in air (Pb, Cd, Zn and Hg), water (Cr, Zn, Cu, Cd, Hg, Pb, Ni and AOX) and soil (nitrate, metals and pesticides). The mean emissions of heavy metals of lead (Pb), cadmium (Cd), zinc (Zn) and mercury (Hg) were 0.0029, 8.12^{-5}, 0.0327 and 7.46^{-5}, respectively, which all four elements showed a decreasing trend with increasing NPK. The average emissions of chromium (Cr), Zn, copper (Cu), Cd, Hg, lead and nickel (Ni) are 0.0010, 0.0023, 0.0003, 6.95^{-5}, 7.67^{-6}, 0.0007 and 0.0002 g, respectively (Table 2). All pollutants which emitted from water showed an enhancing trend with increasing NPK. All heavy metals released to the climate were higher with more NPK values, which indicates that the levels of these pollutants are more affected by the output (performance) that the optimal management of consumption of these elements is necessary. Average nitrate release to soil (2.53 g), metals to soil (2.99^{-6} g Cd eq), pesticides to soil (0.0280 g active ingredient), nitrogen oxide release (1.17 g), sulfur oxide (1.91 g SO_2 eq), NH_3 (0.2148 g), dust (0.6403 g), chemical oxygen demand (4.454 g), phosphorus (0.0405 g) and nitrogen (0.0450 g) that it was found that all these indicators except the release of pesticides with increasing NPK values showed a decreasing trend (Table 2).

Table 2. Life cycle assessment of rice production under NPK fertilizers by impact categories of Ecopoint 97 models

Impact categories	Unit	$N_{250}P_{150}K_{150}$	$N_{200}P_{100}K_{100}$	$N_{150}P_{75}K_{75}$	$N_{100}P_{50}K_{50}$	$N_0P_0K_0$	Mean	SE	CV (%)
NOx	g	1.28	1.22	1.21	1.102	1.05	1.17	0.0340	7.08
SOx	g SO_2 eq	2.12	1.99	1.969	1.784	1.70	1.91	0.0610	7.80
NH3	g	0.2291	0.2207	0.2229	0.2040	0.1972	0.2148	0.0049	5.62
Dust PM10	g	0.7130	0.6680	0.6575	0.5947	0.5681	0.6403	0.0213	8.15
CO_2	g CO_2 eq	490.42	468.88	470.32	429.07	413.56	454.45	11.64	6.27
Pb (air)	g	0.0034	0.0031	0.0030	0.0027	0.0025	0.0029	0.0001	9.55
Cd (air)	g	9.27469E-05	8.54949E-05	8.28679E-05	7.44119E-05	7.05526E-05	8.12148E-05	3.23524E-06	9.75
Zn (air)	g	0.0373	0.0344	0.0334	0.0300	0.0284	0.0327	0.0012	9.65
Hg (air)	g	8.47054E-05	7.8425E-05	7.63387E-05	6.86863E-05	6.52618E-05	7.46834E-05	2.83967E-06	9.31
COD	g	4.5096	4.47	4.63	4.29	4.19	4.42	0.0645	3.57
P	g	0.0458	0.0425	0.0415	0.0373	0.0355	0.0405	0.0015	9.08
N	g	0.0516	0.0474	0.0459	0.0411	0.0389	0.0450	0.0018	10.03
Cr (water)	g	0.0012	0.0011	0.0011	0.0009	0.0009	0.0010	4.01192E-05	9.17
Zn (water)	g	0.0026	0.0024	0.0023	0.0021	0.0020	0.0023	8.22645E-05	8.69
Cu (water)	g	0.0003	0.0003	0.0003	0.0002	0.0002	0.0003	8.82195E-06	8.20
Cd (water)	g	7.88193E-05	7.30094E-05	7.10992E-05	6.39856E-05	6.08089E-05	6.95445E-05	2.63094E-06	9.26
Hg (water)	g	8.50125E-06	7.98838E-06	7.88617E-06	7.14231E-06	6.8329E-06	7.6702E-06	2.46189E-07	7.86
Pb (water)	g	0.0008	0.0007	0.0007	0.0007	0.0006	0.0007	2.45825E-05	8.21
Ni (water)	g	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	3.60652E-06	4.33
Nitrate (soil)	g	2.534949548	2.54	2.67	2.48	2.43	2.53	0.0318	3.07
Metals (soil)	g Cd eq	0.0001	0.0001	0.0001	9.2338E-05	8.85218E-05	9.87856E-05	2.99256E-06	7.42
Pesticide soil	g act.subst.	0.0258	0.0274	0.0300	0.02843	0.0284	0.0280	0.0005	4.91

The results of the input energies and GWP showed a direct correlation between both aspects. In fact, non-renewable energies are ecologically very important, as most non-renewable energies are derived from fossil fuels, so reliance on this resource in the future brings many risks, including the lack of sustainability. Although most impact categories depend on the cultivars, the inputs and paddy field practices were statistically significant. In fact, the main reason for the differences in input energies and emission of GHGs between different amounts of NPK fertilizers was varied use of fertilizers, management practices and chemical pesticides. In this regard, the emission of GHGs occurs during different agricultural practices directly via utilization of fossil fuel during agricultural practices (transplanting to harvesting), or indirectly during the production and transfer of the field's needed inputs (herbicides, pesticides and chemical fertilizers) (Wood and Cowie, 2004). Agricultural and non-agricultural practices such as the production and transfer of fertilizers and pesticides in rice production play roles in global warming by producing 80-98 and 16-91 kg CO_2 eq ha^{-1}, respectively (Pathak and Wassmann, 2007). Different natural and human causes create global warming but global warming is mostly considered to be due to an increase in emission of greenhouse gases because of human activities (Bare, 2011), which induces many changes in global climate patterns. In order to report the amount of produced GHGs, all the produced gases with a CO_2 equivalent, which reflects the GWP, are reported. Nabavi-Pelesaraei et al. (2018) demonstrated that diesel, at 44.34%, had the highest share of energy utilization in paddy rice production in Guilan province, and total energy input was equal to 51585 MJ ha^{-1}. In another study in rice diesel-based production in Iran, diesel accounted for about 46.41% of the total energy utilization in Guilan province, and 29.67% of total energy utilization in Mazandaran province (Kazemi et al., 2015). Pishgar-Komleh et al. (2011) showed that the largest energy utilization in rice production was related to fuel (46% of total energy utilization) which included diesel, natural gas and electricity. Soltani et al. (2013) reported the emissions with GWP to be 621 kg CO_2 eq for producing a ton of wheat in Gorgan, Iran. GWP impact category in the farming section was reported to be 119.5 kg CO_2 eq for wheat production in China (Wang et al., 2009), 1484-1847 kg CO_2 eq for rice in Rasht, Iran (Nabavi-Pelesaraei et al., 2014), and 381 kg CO_2 eq for wheat in Switzerland (Charles et al., 2006).

The demand for non-renewable energy in wheat production in Gorgan, Iran was 6641 MJ t^{-1} (Soltani et al., 2013). The total energy utilized, which depended on the type of soil and field practices and production systems, was 274 to 557 MJ t^{-1} in the UK (Tzilivakis et al., 2005), and 521 MJ t^{-1} for sugar beet production in Japan (Koga, 2008). The reason for the high or low share of non-renewable energy in different scenarios was the difference in fuel usage, fertilizer, and machinery performance, which was also reported by other researchers on similar issues (Pazouki et al., 2017). The emission of NH_3 from urea fertilizer is significantly more than other fertilizers. Urea fertilizer is used excessively in Iran, and there is little use of other sources of fertilizers. The most important substances with acidification potential in ecosystems are SO_2 and nitrogen oxide, which are produced through the utilization of fossil fuels in the process of agricultural production (Engstrom et al., 2007; Iriarte et al., 2010). NH_3, caused by the application of chemical fertilizers in the field, is also an important cause of acidification (Engstrom et al., 2007). These emissions cause acidification through complex processes of atmospheric and chemical transfer, which damages ecosystems, plants, and animal populations (Bare et al., 2003). In China, the characterization index of the impact category of acidification for rice crop was 4 kg SO_2 eq (Wang et al., 2009). In Chile, the impact category of acidification for canola and sunflower production was 19 and 23 kg SO_2 eq (Iriarte et al., 2010). The main reason for these results are varied application of chemical fertilizers and agricultural management practices in different NPK application. It is believed that emissions of CFCs and halogen gas damage the ozone layer in the stratosphere (Nabavi-Pelesaraei et al., 2018). Eutrophication is dependent on the environmental impacts of releasing excessive amounts of nutrients, which changes the species combination of ecosystems and increases the production of biomass. This is followed by damaging consequences, such as decreased biodiversity, and production of chemical compounds that are toxic to humans, livestock, and other mammals (Pishgat-Komleh et al., 2011). Nemecek and Kagi (2007) reported that the volume of eutrophication (section leaching) was 0.59 kg N t^{-1} of sugar beet in Switzerland. In Chile, the characterization index of eutrophication for canola and sunflower production was 7.2 and 9 kg PO_4 eq, respectively (Iriarte et al., 2010).

CONCLUSIONS

In this research, the environmental impacts related to the production of local ('Tarom Hashemi') rice cultivar in different NPK fertilizer application was estimated using the life cycle assessment method. All impact categories and indices of pollutants' emissions were investigated using different methods. Our results demonstrated that an average amount of CED and CExD was 11549.78 and 13443.08 MJ, respectively, that with increase of nitrogen consumption, both indices showed enhancing trend. All pollutants released into the air and the water demonstrated enhancing trend with increasing NPK amounts. The emission of nitrate into soil, metals into the soil, and chemical oxygen demand showed enhancing trend with increasing NPK levels. Therefore, enhancing the emission of pollutants by increasing NPK consumption can be due to increase of yield.

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