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RETRACTED: Environmental Impact of Peanut (*Arachis hypogaea* L.) Production under Different Levels of Nitrogen Fertilization

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Abstract: A field experiment was conducted in Astaneh-ye Ashrafieh of Guilan Province in northern Iran to evaluate the environmental impact of peanut (*Arachis hypogaea* L.) production under three levels of nitrogen (N) use (0, 30, and 60 kg ha^{-1}) applied in the form of urea fertilizer. Six categories of environmental impact (i.e., global warming potential, acidification potential, terrestrial eutrophication potential, depletion of fossil resources, potassium resources, and phosphate resources) were determined. The functional unit was assumed the production of one ton of peanut pod yield. Peanut pod yield increased by 48.8% with N rate 30 kg ha^{-1} and by 108.6% with N rate 60 kg ha^{-1}, compared with control (without N fertilization). The environmental index (EcoX) values with regard to global warming, acidification, and terrestrial eutrophication potential were 0.18, 0.52, and 0.66 for N rates of 0, 30, and 60 kg ha^{-1}, respectively. Increase in N rate aggravated the emission of NH_3 and N_2O, resulting in more harmful effect of peanut growth on the environment at higher N rates than control (without N fertilization). The resources depletion index (RDI) values with regard to depletion of fossil resources, potassium resources, and phosphate resources were 0.80, 0.53, and 0.30 for N rates of 0, 30, and 60 kg ha^{-1}, respectively. Increase in N rate and the resultant higher peanut yield mitigated the environmental effects of fertilization mainly by reducing the depletion of phosphate resources. Proper N input is a major consideration for mitigating environmental impacts of N fertilization in crop production and producers should be informed to use the least rate that will give them an economic optimum return over the long run.

Keywords: depletion of resources; eutrophication; global warming; life cycle assessment (LCA)

1. Introduction

Nitrogen (N) is a major element in crop production throughout the world. This nutrient is the most crucial for upgrading soil fertility and improving crop productivity [1]. The application of urea has been a common practice in Iran in recent years to meet crop N requirements and increase yields. However, N mainly supplied in the form of urea fertilizers is among the most highly consumed energy resources for crop production in Iran, as shown in previous studies [2]. The application of chemical fertilizers has adverse impacts on the environment in terms of different categories [3–5], such as nutrient leaching, salinity and acidification of agricultural soils, emission of greenhouse gases, and accumulation of chemical residues [6,7]. Therefore, appropriate use of fertilizers in agriculture is essential for limiting the environmental impact of conventional farming [8].

Peanut (*Arachis hypogaea* L.) is a significant oil and food crop, grown mainly for the production of oil (seed oil 43–55%) and protein (seed protein 25–28%) [9]. The crop is cultivated primarily for human consumption and has several uses either as whole seeds or as a processed product for use

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in peanut butter, oil, and other products. The cultivation of peanut globally covers a total area of 24.07 million ha, most of which (11.45 million ha) is located in Asia. The global production of peanut pods is 37.64 million tons per annum [10]. In Iran, the planting area of peanut is about 3000 ha, with Guilan Province being the leading producer with 2800 ha of peanut farms [11]. Despite its popularity as a crop and the great part of land devoted to its cultivation, the environmental impact of peanut production has not been studied extensively in the literature. However, previous research from Iran showed that peanut production had severe negative effects on the environment in terms of depletion of fossil resources and global warming potential [12]. Moreover, the environmental impacts of other production systems, such as wheat [4] and saffron [13], have been studied in Iran.

There are available reports about the effect of N fertilization on peanut yield in Iran [14], but no study has examined the environmental impact of peanut production based on the applied N fertilizer. Peanut gets most of its N needs from N-fixing bacteria colonizing the plant's roots, but natural or artificial inoculation does not always perform adequately, so that growers apply some N at sowing to prevent such a case. In the assessment of environmental impacts of wheat production in Iran, application of N rates up to 220 kg ha^{-1} improved grain yield under irrigated ecosystems, whereas application of N rates up to 60 kg ha^{-1} improved grain yield under rain-fed ecosystems [4]. However, higher rates had no major effect on grain yield, implying potential environmental impact [4]. Similarly, fertilization in saffron production had the greatest environmental impact considering the eutrophication impact category [13]. Peanut is cultivated in large areas in Iran, but data on its environmental effect based on crop fertilization do not exist. This study attempted to examine for the first time the environmental impact for peanut growth with urea fertilization in Guilan Province of Iran on the basis of the life cycle assessment (LCA) methodology. In particular, the objective of the present research was to assess the environmental impact of different N (urea) rates used for peanut production in Astaneh-ye Ashrafiyeh, Iran, using the LCA methodology.

2. Materials and Methods

2.1. Crop Establishment and Agronomic Practices

The study was carried out in Astaneh-ye Ashrafieh (lat. 37°16' N, long. 49°56' E, altitude about 3 m), near to the Caspian Sea in northern Iran in 2015. To estimate soil attributes of the experimental field, six soil samples (from the depth of 0–30 cm) were randomly taken at different areas of the field and then a combined sample was sent for soil analysis. The soil was classified as loamy with physico-chemical attributes presented in Table 1. The seedbed was prepared according to standard tillage practices, including semi-deep plowing and disking in early spring. Light (secondary) soil tillage with a rotary cultivator was performed before sowing to pulverize soil.

Table 1. Basic soil characteristics.

Characteristic	Value/Group
Texture	Loamy
Clay (%)	20.5
Silt (%)	32.5
Sand (%)	47.0
Electrical conductivity (µS cm^{-1})	196.7
pH	7.67
Total nitrogen (%)	0.053
Absorbable potassium (ppm)	164.7
Absorbable phosphorus (ppm)	2.5

Peanut cv. "North Carolina 2" seeds were manually sown under rain-fed conditions in mid-May 2015. Since "North Carolina 2" is the cultivar commonly used the region, the study employed the same cultivar, which had been identified and selected by the Oilseed Research Department of Seed and

Plant Improvement Institute in Lasht-e Nesha Station of Guilan in 1977 [15]. Before sowing, the seeds were disinfected with Thiram fungicide at a ratio of 2:1000 (v/v). The seeds were dry-sown in a square arrangement with 40 × 40 cm^2 spacing, at the depth of 4 cm, on 13 May [16–18]. The population corresponded to 62,500 plants ha^{-1}. The experiment was established in a randomized complete block design (RCBD) with three replications. Plot area was 12 m^2. The treatments included three rates of N (0, 30, and 60 kg ha^{-1}) as urea (46% N) at sowing time. N fertilizer treatments were applied in strips with about 10 cm spacing from the seeds at the depth of 5–10 cm. Peanut get most of its N needs from N-fixing bacteria colonizing the plant's root system, but natural or artificial inoculation does not always perform adequately, so that growers apply 30 to 60 kg N per ha at sowing to prevent such a case. Phosphorous (P_2O_5) and potassium (K_2O) were also applied in strips between rows at the depth of 5–10 cm and at rates of 25 and 20 kg ha^{-1}, respectively. P_2O_5 and K_2O were supplied with a triple superphosphate fertilizer (containing 46% P_2O_5) and a potassium sulfate fertilizer (containing 50% K_2O), respectively. Severe pest or disease problems did not occur in the growing season. Therefore, no prophylactic or need-based pesticide applications were performed. Weeds were managed manually twice before flowering during the growing season. Plants were harvested on 22 September 2015. At harvest, plants from a 1-m^2 area were dug up; all pods were detached from the plants and counted. To determine peanut pod yield, the detached pods were exposed to open air (for reducing moisture) for one week. Afterwards, they were oven-dried at 70 °C until constant weight to determine their dry weight, using a 0.01-precision digital balance. Finally, pod yield was expressed as kg per unit area. Basic weather data during the experiment are given in Table 2.

Table 2. Basic weather data during the experiment.

Month	Mean Temperature (°C)		Total Rainfall (mm)		Sunshine Hours per Day	
	Growing Season	10-Years Average	Growing Season	10-Years Average	Growing Season	10-Years Average
May	21.7	20.2	0.4	1.4	6.8	6.6
June	24.7	23.4	0.1	2.3	9.9	7.3
July	26.4	25.3	3.7	2.1	8.7	7.3
August	26.3	25.2	1.7	3.4	6.5	6.3
September	24.0	23.2	2.1	5.0	6.0	4.6

2.2. *LCA Methodology*

The method operated in accordance with ISO14040 and is, in general, divided into four phases: (i) definition of goal and functional unit; (ii) life cycle inventory; (iii) assessment; and (iv) interpretation of environmental impact [19,20]. Below is a description of these four phases.

2.2.1. Goal and Functional Unit Definition

The first phase of LCA was to define the goal and the functional unit. The functional unit relates the inputs and outputs to each other, providing conditions for comparison [21,22]. The goal of the present research was to study the environmental consequences of peanut growth with different N fertilization rates on global warming potential, acidification potential, terrestrial eutrophication potential, depletion of fossil resources, phosphate resources, and potassium resources during peanut growing and drying. The functional unit was assumed the production of one ton of peanut pod yield.

2.2.2. Life Cycle Inventory

In this phase, all resources and quantities required for the studied crop production and also all quantities of pollutants emitted to the environment by the use of these inputs were calculated in terms of reference units.

System Inputs

Generally, four inputs with environmental polluting potential are used for crop production in Iran: diesel fuel, N, phosphate, and potassium fertilizers [12,23,24]. The full-tank method was used to quantify the diesel fuel used for peanut production, including drying. This means that all machines operated with a fuel tank that was completely full and the rate of fuel decline in each stage was recorded. In total, diesel fuel was estimated to be 172.5 L m^{-1} ha^{-1}. The quantities of the consumed fertilizers per functional unit were given by the experimental design. The estimated coefficient of energy equivalent to peanut yield is presented in Table 3 [25,26]. In this study, peanut hull was taken at 25% of the total weight of peanut, according to a previous study [25]. Finally, the quantities of consumed diesel fuel and N, P, and K fertilizers were calculated for the production of one ton of peanut pod yield.

Table 3. Yield components of peanut and their energy.

Yield Type	Energy Equivalent (MJ kg^{-1})	Reference
Seed	25.00	Ozkan et al. [25]
Hull	19.33	Fasina [26]

Pollutant Emissions

According to LCA, the emissions from peanut production were divided into off-farm and on-farm pollutants [27].

Pollutant Emissions before Feeding Inputs to Farm

In the LCA methodology it is not sufficient to know what the input consists of, but we must know what environmental impact the input can cause [28]. So, the emissions before the feeding of inputs, including those emitted during extraction, refinery and transportation of inputs, were inferred from SPINE@CPM [28]. These include emissions during the raw material extraction, processing (refinery), and transportation of inputs. Transportation work is recorded as inputs of the total amount of transport-work for all different materials used in the production process by different means of transport. Data for extraction and processing of raw materials are not easily accessible. Also, it is not possible to distinguish the specific transport-work for a specific material and, therefore, data for the extraction and processing of raw material along with data for the transportation of inputs are often taken from databases.

On-Farm Emissions from Diesel Fuel Consumption

According to a previous research [29], the combustion of one L of diesel fuel emits 2.73 kg CO_2, 18.1×10^{-6} kg N_2O, and 173×10^{-6} kg CH_4. The emission rate of NO_X and SO_2 is 22.2×10^{-3} and 4×10^{-3} kg per one L of diesel fuel, respectively [30].

Direct Emissions of N Compounds from Urea

One of the major emissions of N fertilizers is ammonia. Nearly 90% of the global emissions of ammonia are linked to the agricultural sector [27]. Due to lack of research, the ammonia emission factor from urea was assumed in the present study to be equal to the mean factor in Europe and the United States. Based on this assumption, about 15% of the total net N consumed in urea fertilizers emits as NH_3-N (a direct function of the fertilizer application amount) [27,31]. N_2O emission is associated with the soil N content and the interaction between soil moisture and soil N availability [32]. Reports of the Intergovernmental Panel on Climate Change (IPCC) mention that 1% of the total N used as fertilizer emits as nitrous oxide N [32]. It has been shown that the emission rate of NO_X to the atmosphere was 10% of that of N_2O [33]. Nutrient leaching was not calculated in this study, assuming that leaching losses of urea N in the field were minimal due to soil application in strips and consistently low rainfall in the growth period (Table 2).

2.2.3. Impact Assessment

The goal of impact assessment is further interpretation of inputs and outputs of peanut systems, including three phases: categorization, normalizing, and weighting [34].

Categorization

At this phase, the emissions to the environment and the resources spent during the life cycle of a specific product are related to their environmental impact as a category and the effective compounds are grouped in their respective categories. The present study assumed six impact categories or life cycle inventory items: global warming potential, acidification potential, terrestrial eutrophication potential, depletion of fossil resources, phosphate resources, and potassium resources. After impact categorization, it is the turn for the index of each impact category to be determined. The index of the impact category *i* is calculated by Equation (1).

$$ICI = \sum_{i}\left[\left(E_j \; or \; R_j\right) \; \times \; CF_{j,i}\right] \tag{1}$$

where E_j or R_j represents the emission of compound *j* or the consumption of resource *j* per functional unit, and $CF_{j,i}$ represents the categorization factor for compound *j* contributing to impact category *i*. The categorization factor of each impact category indicates the potential of that compound in generating the respective impact. Table 4 presents the efficiency of the compounds.

Table 4. Classification of impacts.

Impact Category	Compound	Potential of Compound	Reference
GW	CH_4, CO_2, N_2O	CO_2 = 1, CH_4 = 21, N_2O = 310	Snyder et al. [32]
AC	NH_3, SO_2, NOx	SO_2 = 1.2, NOx = 0.5, NH_3 = 1.6	Brentrup et al. [34]
TE	NH_3, NOx	NH_3 = 4.4, NOx = 1.2	Nikkhah et al. [12]
DFoR	Diesel fuel consumption	56.31	Taheri-Rad et al. [35]
DPhR	P consumption	0.25	Brentrup et al. [34]
DPoR	K consumption	0.105	Brentrup et al. [34]

GW: global warming (kg CO_2 eq), AC: acidification, (kg SO_2 eq), TE: terrestrial eutrophication (kg NOx eq), DFoR: depletion of fossil resources (MJ), DPhR: depletion of phosphate resources (kg P_2O_5 eq), DPoR: depletion of potassium resources (kg K_2O eq).

Normalizing

After the categorization index was determined for each impact category, the quantities were normalized for better understanding and comparison of the categorization index of each category with reference indices. In this step, we wanted to make the data dimensionless [34]. The normalizing factor of the impact categories is presented in Table 5. The categorization index was divided by normalizing factors to yield normalizing indices.

Weighting

The damage potential of each impact category was reflected into weighting factors. High values of the factors indicate high potential of the category to damage the environment. The weighting factors of the impact categories are shown in Table 4. The final index was calculated by multiplying normalizing indices with weighting factors [36].

Table 5. Weighting and normalization factors.

Impact Category	Normalization Factor (Unit)	Weighting Factor	Reference
GW	8143 (kg CO_2 eq)	1.05	Mirhaji et al. [23]
AC	52 (kg SO_2 eq)	1.80	Mirhaji et al. [23]
TE	63 (kg NOx eq)	1.40	Mirhaji et al. [23]
DFoR	39167 (MJ)	1.14	Mirhaji et al. [23]
DPhR	7.66 (kg P_2O_5 eq)	1.20	Brentrup et al. [27]
DPoR	8.14 (kg K_2O eq)	0.30	Brentrup et al. [27]

GW: global warming (kg CO_2 eq), AC: acidification, (kg SO_2 eq), TE: terrestrial eutrophication (kg NOx eq), DFoR: depletion of fossil resources (MJ), DPhR: depletion of phosphate resources (kg P_2O_5 eq), DPoR: depletion of potassium resources (kg K_2O eq).

2.2.4. Impact Interpretation

The impact categories of global warming, acidification, and terrestrial eutrophication belong to the environmental index (EcoX), whereas the impact categories of the depletion of phosphate, potassium, and fossil resources belong to the resource depletion index (RDI). The latter impact categories are a challenge for future generations, whilst the impact of the former categories becomes visible in a relatively short term [36].

Environmental Index (EcoX)

The higher the EcoX is, the higher the potential to harm the environment will be. The product of normalizing results of each impact category, the respective weighting factor, and their summing yields the EcoX of that product or system, which was calculated according to Equation (2) [21].

$$\text{EcoX} = \sum_i [E_i \times WF_i] \tag{2}$$

where EcoX represents the environmental index per functional unit, E_i represents the normalizing results for the impact category i per functional unit, and WF_i represents a weighting factor for the impact category i.

Resource Depletion Index (RDI)

The more the impact categories for resource depletion are, the more severe the perils for the next generations will be. Like the EcoX, the resource depletion index (RDI) for a specific product or system was calculated by multiplying the normalizing results of each impact category of resource depletion with the respective weighting factor and then summing, as reflected in Equation (3) [34].

$$\text{RDI} = \sum_i [E_i \times WF_i] \tag{3}$$

where RDI accounts for the resource depletion index per functional unit, E_i is the normalizing results for impact category i per functional unit, and WF_i is the weighting factor for each impact category i.

The statistical analyses were performed by MSTAT-C Software Package and the means were compared with the LSD test at $P < 0.01$. The LCA analyses were performed by MATLAB Software Package.

3. Results and Discussion

Mean temperature, total rainfall, and sunshine duration during the experiment were normal for the area as compared with the 10-years average (Table 2). Peanut yield increased significantly with increasing N rates (Table 6). As it can be observed, the total yield was 1684.00, 2505.33, and 3513.33 kg ha^{-1} at the N rates of 0, 30, and 60 kg ha^{-1}, respectively. Previous research in the area showed that the application of 52 kg N ha^{-1} resulted in peanut yield of 3210 kg ha^{-1} [12], which is comparable with yield data of the present study. Increased rate of N paves the way for increase in leaf chlorophyll content, resulting in higher yields. In a similar study, the highest mean pod yield of peanut was related to N fertilization rate of 60 kg ha^{-1} [14].

Table 6. Peanut yield in different nitrogen rates.

Yield Type	Control	30 kg/ha N	60 kg/ha N
Seed yield (kg ha^{-1})	1263.00	1879.00	2635.00
Hull yield (kg ha^{-1})	421.00	626.33	878.33
Total pod yield (kg ha^{-1})	1684.00	2505.33	3513.33

The consumption rate of four inputs (i.e., diesel fuel, N, phosphorous, and potassium) for the production of one ton of peanut yield is presented in Table 7. The study considered the depletion of fossil resources of diesel fuel for the production and drying of peanuts. As evident, higher N rate reduced the diesel fuel consumed for the production of one ton of peanut yield. In total, the fuel volume consumed for the production of a ton of peanut yield in the current study was higher than that reported for rice [37], but lower than that reported for soybean [38]. N consumption rate at the three applied levels in the present study was 0, 11.97, and 17.08 kg per ton of peanut yield (Table 7). Since all experimental plots were fertilized with the same rates of P and K fertilizers, their consumption rates per one ton of crop yield decreased as peanut yield increased. Mean consumption rates of P and K were 10.65 and 8.46 kg per ton of peanut yield, respectively (Table 7). The respective values in a previous study in the area were 7.44 and 6.81 kg per ton of peanut yield [12]. Also, P and K consumption rates were 24.56 and 19.86 kg per ton of peanut yield, respectively, in a peanut monocropping system and 12.59 and 9.95 kg per ton of peanut yield, respectively, in a peanut-bean intercropping system [39].

Table 7. N, P, K and diesel fuel for one ton production of peanut.

Input	Control	30 kg/ha N	60 kg/ha N	Mean
Diesel fuel (L)	102.43	68.85	49.10	73.46
N (kg)	0.00	11.97	17.08	9.68
P_2O_5 (kg)	14.85	9.98	7.12	10.65
K_2O (kg)	11.88	7.98	5.69	8.46

The amount of emissions by peanut growth and yield in terms of different N treatments is shown in Table 8. It can be observed, as N rate increased, more NH_3 and N_2O were emitted, while NOx, CO_2, CH_4, and SO_2 showed a decreasing trend. The characterization indices of impact categories for the production of one ton of peanut yield are presented in Table 9. Normalization indices and the weighting factors that are used to calculate EcoX and RDI are also shown in these tables. The global warming potential of the production of one ton peanut yield was estimated at 341.53, 370.57, and 364.92 kg CO_2 eq for the three N rates of 0, 30, and 60 kg ha^{-1}, respectively (Table 9). In a previous study, this value was reported to be 311 kg CO_2 eq for the production of one ton peanut yield [12], whereas this value was 254.73 and 174.43 kg CO_2 eq in a peanut monocropping system and a peanut-bean intercropping system, respectively [39]. The characterization index of acidification potential for the production of one ton of peanut yield was 2.15, 5.42, and 6.71 kg SO_2 eq at the three N rates of 0, 30, and 60 kg ha^{-1}, respectively (Table 9). In a previous study, this value was reported to be 6.25 kg SO_2 eq with a mean N rate of 52 kg ha^{-1} [12]. According to Firouzi and Nikkhah [39], this value was 5.88 and 3.59 kg SO_2 eq in a peanut monocropping system and a peanut-bean intercropping system, respectively. The characterization index of terrestrial eutrophication potential was 2.96, 12.86, and 16.93 kg NOx eq at the three N rates of 0, 30, and 60 kg ha^{-1}, respectively (Table 9). This value has been reported to be 16.22 kg NOx eq at a N rate of 52 kg N ha^{-1} [12]. Depletion of fossil resources was 5767.83, 3876.94, and 2764.72 MJ under the N rates of 0, 30, and 60 kg ha^{-1}, respectively (Table 9).

Also, the depletion of phosphate resources was 3.71, 2.50, and 1.78 kg P_2O_5 eq, whereas the depletion of potassium resources was 1.25, 0.84, and 0.60 kg K_2O eq under the studied N rates, respectively (Table 9).

After the classification of the normalization results presented in Table 8, EcoX was calculated for the production of one ton of peanut yield, as shown in Figure 1. The EcoX per one ton of peanut production including global warming, acidification, and terrestrial eutrophication was 0.18, 0.52, and 0.66 at the N rates of 0, 30, and 60 kg ha^{-1}, respectively. Overall, the environmental impact categories (global warming potential, acidification potential, and terrestrial eutrophication potential) were the most harmful to the environment at higher N rates than the non-fertilized control. In another study in Guilan Province, it was reported that a N rate of 52 kg ha^{-1} resulted in EcoX of 0.62 per one ton of peanut production [12]. In a wheat production system treated with 144 kg N ha^{-1} and considering four environmental impacts (i.e., global warming potential, acidification potential, terrestrial eutrophication potential, and land use change), the EcoX was estimated at about 0.2 [27]. Brentrup et al. [40] asserted that the EcoX was low under N rates of as low as 150 kg ha^{-1}, but it was sharply increased as N rate was increased from 200 to 390 kg ha^{-1}. The RDI per one ton of peanut production was found to be 0.80, 0.53, and 0.30 at the N rates of 0, 30, and 60 kg ha^{-1}, respectively, when the consumption of diesel fuel, phosphate, and potassium was taken into account (Figure 2). In another study, the RDI was estimated at 3.61 and 2.69 for a peanut monocropping system and peanut-bean intercropping system, respectively [39].

Table 8. Outputs for one ton of peanut production.

Emission Source	Emission Pollutant	Control	30 kg/ha N	60 kg/ha N
		Amount of emission (kg per 1000 kg peanut)		
Urea fertilizer	NH_3	-	2.456	3.505
Urea fertilizer	N_2O	-	0.419	0.597
Diesel fuel	N_2O	0.003	0.002	0.001
Urea fertilizer	NO_X	-	0.056	0.080
Diesel fuel	NO_X	2.393	1.608	1.147
Urea fertilizer	CO_2	-	10.988	15.679
Diesel fuel	CO_2	320.511	215.436	153.637
Urea fertilizer	CH_4	-	0.010	0.015
Diesel fuel	CH_4	0.472	0.317	0.226
Urea fertilizer	SO_2	-	0.016	0.023
Diesel fuel	SO_2	0.647	0.435	0.310

Table 9. Impact assessment for producing one ton peanut.

Impact Category	Characterization Index			Normalization Index			Final Index		
	0 N	30 N	60 N	0 N	30 N	60 N	0 N	30 N	60 N
GW	341.53	370.57	364.92	0.04	0.05	0.04	0.04	0.05	0.05
AC	2.15	5.42	6.71	0.04	0.10	0.13	0.07	0.19	0.23
TE	2.96	12.86	16.93	0.05	0.20	0.27	0.07	0.29	0.38
DFoR	5767.83	3876.94	2764.72	0.15	0.10	0.07	0.17	0.11	0.08
DPhR	3.71	2.50	1.78	0.48	0.33	0.23	0.58	0.39	0.28
DPoR	1.25	0.84	0.60	0.15	0.10	0.07	0.05	0.03	0.02

GW: global warming (kg CO_2 eq), AC: acidification, (kg SO_2 eq), TE: terrestrial eutrophication (kg NOx eq), DFoR: depletion of fossil resources (MJ), DPhR: depletion of phosphate resources (kg P_2O_5 eq), DPoR: depletion of potassium resources (kg K_2O eq).

The analysis of variance for the EcoX and the RDI indicated significant differences in acidification potential, terrestrial eutrophication potential, depletion of fossil resources, phosphate resources, and potassium resources among different N treatments at $p < 0.01$ (Table 10). As higher N rate resulted in higher peanut production per unit area, it aggravated the environmental damages in global warming, acidification, and terrestrial eutrophication impact categories (Figure 1). Therefore, the increase in N rate deteriorated the harmful influences in the environmental impact categories (i.e., global warming, acidification, and terrestrial eutrophication). Also, higher N rate and the resultant higher peanut yield mitigated the environmental effects in the impact categories of fossil resources depletion and phosphate and potassium resources depletion (Figure 2). Although higher N rate reduced the impact categories of the depletion of resources per production unit through improving yield per unit area, it cannot mitigate the challenges faced by future generations because resources depletion remains constant in a certain production time span. In general, LCA of fertilizers shows that despite progress in fertilizer manufacturing and use in the last 100 years, high intensity of production promotes pollutants emissions, contributing to the greenhouse effect, acidification, and eutrophication.

Table 10. Effect of nitrogen of peanut yield and its environmental impacts (for one ton peanut).

Variance	df	GW	AC	TE	DFoR	DPhR	DPoR
Replication	2	459.839	0.039	0.144	99,468.304	0.041	0.005
Nitrogen	2	678.219 ns	16.535 **	155.088 **	70,114,840.672 **	2.905 **	0.328 **
Error	4	426.741	0.070	0.395	78,242.815	0.032	0.004
CV (%)		5.74	5.54	5.74	6.74	6.75	6.77

GW: global warming (kg CO_2 eq), AC: acidification, (kg SO_2 eq), TE: terrestrial eutrophication (kg NOx eq), DFoR: depletion of fossil resources (MJ), DPhR: depletion of phosphate resources (kg P_2O_5 eq), DPoR: depletion of potassium resources (kg K_2O eq); ** Significant at $P < 0.01$; ns: non-significant.

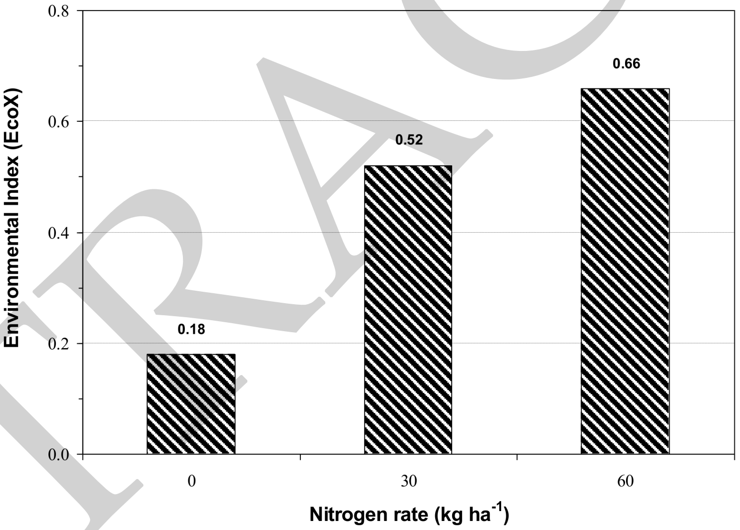

Figure 1. Environmental index (EcoX) for the production of one ton of peanut yield.

Data of this study provide novel evidence for the environmental impact of peanut production with different fertilization levels of N in northern Iran, for which no data exist in the literature. There was an increase in peanut yield with increasing N rate, but the EcoX with regard to global warming, acidification, and terrestrial eutrophication also increased for the N rates of 30 and 60 kg of N per ha, compared with the non-fertilized control. Increases in N rate aggravated the emission of NH_3 and N_2O, resulting in more harmful influence of peanut production on the environment at higher N rates. On the other hand, the RDI with regard to depletion of fossil resources, potassium resources, and phosphate resources decreased at 30 and 60 kg of N per ha, compared with the non-fertilized control, revealing that higher N rate and the resultant higher peanut yield mitigated environmental effects in the impact categories of fossil resources depletion and phosphate and potassium resources depletion. Evidently, proper fertilization based on crop requirements for nutrients enables optimal yields, ensures efficient land use, and limits nitrate losses [41]. Regarding eco-efficiency, it seems that the best results are achieved in medium-intensity production systems [42]. However, a reduction in abiotic resources consumption does not always produce the expected results. Using organic fertilizers or waste derived from fermentation of biomass, instead of the widely used mineral fertilizers, had limited resource consumption, but promoted losses of nutrients, thus causing eutrophication and acidification [42]. An increase in fertilizer use efficiency is achieved in most agriculturally advanced regions, but this progress can be due to major improvements in cultivation practices, techniques of fertilizer application, and use of modern crop varieties. Therefore, despite some progress in coated, controlled release fertilizers, and nitrification inhibitors, a significant change in the fundamental nature of main fertilizer products remains limited for many years or even decades.

This study provided an assessment of the environmental impact of N rates used for peanut production in northern Iran, using the LCA methodology. The LCA methodology can be helpful in improving fertilizer use in farming by comparing alternative products and aiding the selection of environmentally friendly technologies that optimally utilize resources for fertilizer use [5]. Similar studies on the environmental impact of N rates in peanut production following the principles of LCA methodology do not exist. Understanding environmental problems that are precisely defined in LCA would represent a novelty for environmental managers. The scope of the study was set at gate-to-gate, limited to farmland cultivation practices and their impact at the local scale with a focus on fertilizations practices of the current cropping system. However, agricultural environmental impacts are not limited to the field and therefore a more extensive evaluation and comparison of the environmental impacts of the cropping system would need to consider off-farm data, such as the production and transportation of materials. In addition, the models used in this study were international models rather than tailored to the regional context and therefore a certain degree of over-generalization in the assessment results may exist. However, given the uncertainty arising from variability of measurements or a lack of data or model assumptions, this study could be seen as a basis for comparisons in future studies and improve the decision-making process, particularly with respect to input data. Future research may be extended to cover different fertilization practices and fertilizer types used in this cropping system, including comparison of the environmental impacts of other chemical fertilizers and organic fertilizers.

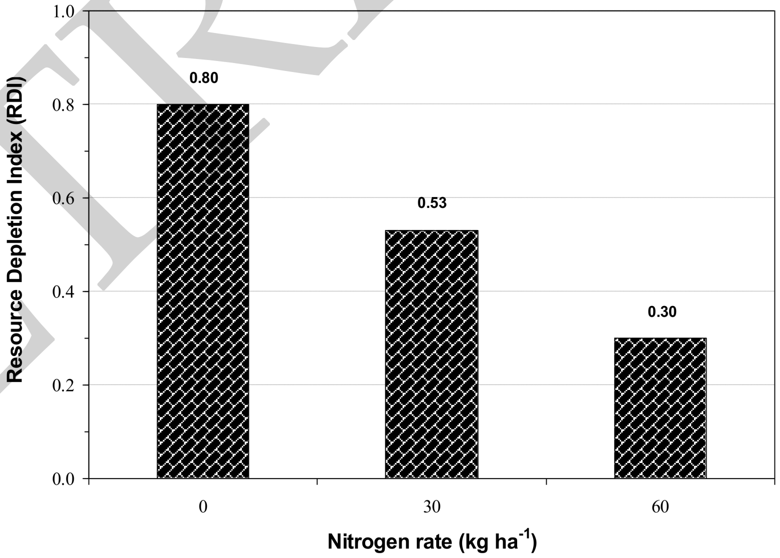

Figure 2. Resource depletion index (RDI) for the production of one ton of peanut yield.

4. Conclusions

The present study dealt with the effects of different N fertilizer rates on peanut growth and environmental impact in northern Iran. An increase in the N rate aggravated the emission of NH_3 and N_2O, resulting in more harmful influence of peanut production on the environment at higher N rates than the non-fertilized control. However, higher N rates mitigated the harmful environmental impacts in resource depletion impact categories. According to the results of this study, replacement of N sources with less pollutant fertilizers could mitigate the undesirable environmental effects on global warming potential, acidification potential, and terrestrial eutrophication potential along with alleviation of adverse environmental effects in resource depletion impact categories. Improvement in fertilizer use efficiency is essential in the current agricultural practice. Proper N input is a major consideration for mitigating environmental impacts of N fertilization in crop production and producers should be informed to use the least rate that will give them an economic optimum return over the long run.

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