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The relative contribution of applied inputs of rapeseed (*Brassica napus* L.) agro-ecosystem on environmental factors

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Abstract

In this study, the environmental impacts of rapeseed production were studied using the SimaPro software. The initial data were collected from 30 farmers in the Alborz Province by face-to-face questionnaire method. The selected functional unit (FU) was one Mton-1 rapeseed production. Five environmental indices were evaluated, including the potential of abiotic depletion, acidification, eutrophication, global warming and ozone layer depletion. To produce each ton of rapeseed, 84 kg of nitrogen, 63 kg of phosphate, 63 kg of potassium, 133.5 l of diesel fuel and 586 kW of electricity were used. Also, the CO_2, CO, N_2O and NOX (different types of oxides of nitrogen) emissions were about 361, 4.1, 11.5 and 4.8 kg per ton of rapeseed respectively. The results indicate that the global warming potential amounts to 1629.52 kg CO_2 eq. Also, the acidification and eutrophication potentials were found to be 8.31 kg SO_2 eq. and 2.73 kg PO_4 eq. respectively. It was also revealed that the chemical fertilizers had the highest contribution among the evaluated inputs within the rapeseed growing period. Overall, this study showed that reducing the consumption of chemical fertilizers, especially nitrogen-based ones, is important for reducing environmental footprints in rapeseed production.

Keywords

Global warming, acidification, eutrophication, ozone layer depletion, abiotic depletion

Introduction

Crops are strongly associated with energy consumption. With the increase in the worldś population and agricultural land constraints and elevation in the standard of living, the energy use in the agricultural sector has also increased to achieve a sustainable increase in the production (1). The input is per unit of output. On the other hand, excessive use of energy has caused some problems for human health and the environment, including today's issues in the world regarding finding sustainable patterns and using energy to conserve fossil fuel resources for future generations and reduce the associated effects. The abuse of burning fossil fuel sources has faced us with a severe challenge (2, 3).

Today, environmentally conscious consumers are particularly susceptible to the environmental indicators from production to consumption;

they are more acceptable commodity with less environmental effect (1). Oilseed crops are the world's second largest food reserves (4). Food and agriculture organization (FAO) statistics show that the rapeseed is the world's third largest source of vegetable oil production in terms of quantity (5, 6) This oilseed is grown in most parts of Iran and its oil content is about 40-45% of total grain weight (7). In addition, rapeseed is currently the most significant source of biodiesel production in the world. Greenhouse gas emissions during the growth period crops are among the factors influencing the human health and the environment. Several studies have been conducted in this field, for example used the SimaPro software model 2000 CML to assess the environmental effects of the beans (8). They reported the electricity and manure as the most influential sources of greenhouse gas emission. Studies are on the level of carbon dioxide emissions in the growth period of rapeseed to produce biodiesel as an alternative to fossil fuels. They analyzed the level of greenhouse gas emissions in three main steps including agricultural production, transportation and industrial conversion (7). Their research showed that the total greenhouse gas emission at all stages of the growth period for biodiesel production was equal to 1054.98 kg CO_2 eq ha^{-1} and the agricultural production stage obtained the first rank. The growth period of the garlic was assessed and evaluated its environmental effects by the SimaPro software (9). The SimaPro software was used to assess the cycle of rose cultivation in Ethiopia (10). They analyzed nine environmental indicators including the evacuation of underground resources (nonliving), acidification potential, global warming potential, ozone depletion potential and human toxicity potential. Their results showed that the highest emissions are associated with chemical fertilizer, especially nitrogen fertilizers. After dispersion of those emissions resulting from the use of pesticides, they mainly affected the terrestrial toxicity index, freshwater toxicity and photochemical oxidation. They also stated that pesticides have no visible effect on the other environmental indicators and proposed the management of using chemical fertilizers and pesticides to improve the living conditions (10). The model +Impact 2002 in the SimaPro software was used to assess the biological effect of the rapeseed production and in accordance with the relevant coefficients, the overall index of the pollutant emission was calculated for rapeseed production (11, 12). The reduction in the fossil fuel resources and detrimental effects of using these fuels on the climate change also make the importance of life cycle assessment more evident in the growth period assessment of the indicators under consideration: (i) non-bio sources /global warming, acidification potential of ozone layer failure and the eutrophication potential.

Materials and Methods

Alborz province is one of the top-10 Iranian provinces under the cultivation of rapeseed, in Savojbalagh and Nazar-Abad being the most significant areas of the province under cultivation. The regions considered for this research have been dedicated to the rapeseed cultivation after wheat and barley. The region under study is located at coordinates of 35.9960° N and 50.9289° E, in the northwest of Tehran province, with a height of 835 m above sea level. Average precipitation of Alborz province is equal to 247.3 mm and the average annual temperature is equal to 14.4 °C. The area has clay loam soil. The data used in the crop year of 2017-2018 were collected by the questionnaires distributed among 30 fields of rapeseed lands in Alborz province (Fig. 1). One hundred hectares of the lands in the region were devoted to rapeseed production during 2016-2017 reflecting the importance of rapeseed production in the region.

Fig. 1. The study area in Alborz province, Iran.

Determining the Purpose and Functional Unit

Information will be obtained by assessing the growth period of the rapeseed production system that will help the farmers, politicians and legislators to take action to reduce the pollutants resulting from the production of this product. The functional unit (FU) selected was one M ton^{-1} of rapeseed production (Table 1, 2).

Table 1. Inventory data for rapeseed production systems per one ton of grain yield

Inputs/Emissions	Unit	Quantity
Inputs		
Irrigation water	m^3	1458.5
Nitrogen (N)	kg	83.5
Phosphate (P_2O_5)	kg	62.5
Potassium (K_2O)	kg	62.5
Pesticide	kg	0.63
Fossil fuel	L	133.5
Electricity	kW	586
Emissions		
Nitrate	kg	11.69
Pesticides	kg	0.189
CH_4	g	23
CO_2	kg	361.1
CO	kg	4.14
N_2O	kg	11.5
NO_X	kg	4.83

Table 2. Values of environmental impacts per one ton of rapeseed grain

Impact categories	Abiotic depletion (kg Sb eq.)	Acidification (kg SO_2 eq.)	Eutrophication (kg PO_4 eq.)	Global warming (kg CO_2 eq.)	Ozone layer depletion (kg CFC-11 eq.)
Rape	0	2.78	1.4	629.54	0
Nitrogen	2.37	1.76	0.21	261.3	0.000036
Potassium	0.43	0.82	0.19	56.28	6.46E-06
Phosphate	0.82	1.67	0.54	100.77	7.20E-06
Pesticide	0.05	0.05	0.017	5.37	0.000019
Diesel	2.75	0.5	0.07	40.14	0.000086
Electricity	3.19	0.73	0.3	536.12	0.000083
Total	9.61	8.31	2.727	1629.52	0.000238

System Boundary

The consumption process and waste disposal by the consumer (because, in Iran, the process of consumption and waste disposal has not yet turned into a systematic approach) were not considered as well as the type of tools and buildings used in the production systems, still the information related to the inputs needed for rapeseed production, energy consumption of rapeseed was considered through reviewing the resources as well as collecting the data from the relevant departments. In this study, the boundary of rapeseed production system was determined from "cradle to farm".

The evaluation of rapeseed growth period in this study included the collection of the required information in order to quantify all the inputs and outputs related to the production of a single rapeseed. The system border was up to the set of agricultural production (Fig. 2). The agricultural set included the farming methods used by the farmer, such as irrigation and its methods, weed control, management of using the fertilizer and pesticides. The data required for this study were divided into 2 primary and secondary data. Preliminary data included the amount of consumed fertilizers and pesticides, the amount of harvested rapeseed, water and electricity consumption for irrigation, fuel consumption for the tractors and other machinery, and so on. These data were collected through observation, sampling and questionnaires. The questionnaires were filled in different villages through face-to-face interviews with the farmers. Climatic and soil data were also collected from the Alborz Agriculture Jihad Organization.

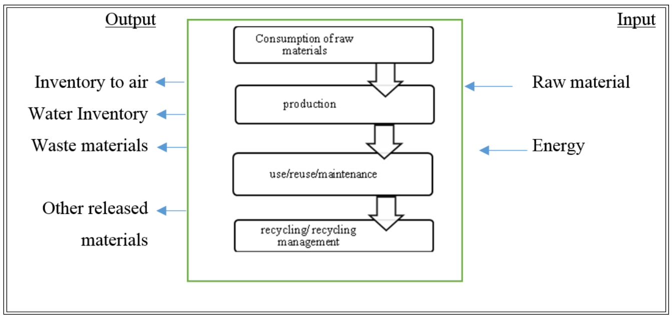

Fig. 2. System boundary and main phases in the rapeseed production in Alborz province.

Secondary data included various data sources, such as international studies to estimate the data that cannot be collected from the farms (such as nitrogen emissions and pesticides and some compounds from the farms) and international databases calculating the use of materials and energy to generate the institutions (such as pesticides and fertilizers). EcoInvent® 3.0 data were used in the SimaPro 8.0.4.30 software to capture the data on fertilizer and pesticide production. The chemical fertilizers used included nitrogen, phosphate and potassium.

System Outputs

The production of agricultural products is usually associated with the emission of three greenhouse gases including carbon dioxide, methane and nitrous oxide (13). Usually, for estimating the emission rate, various nitrogenous compounds are considered as the fuel consumed in the farm. Accurate measurements of these emissions, along with taking into account the financial and temporal differences in the results will be neither practical nor appropriate for the growth period assessment objectives. Distribution varies depending on the soil type, climate and farm management system therefore, instead of measurements; organized methods are used to estimate the average emission rate as also used in this study (14).

Fertilizers

Most fertilizers used in the farms of Alborz province included nitrogen, potassium, phosphate, and manure. Methods used in the international papers were used to estimate the direct emissions from the rapeseed (including nitrogen compounds and phosphorus). According to one report, fertilizer production accounts for 1.2% of total greenhouse gas emissions; 0.2% as CO_2, 0.2% as N_2O, and 0.2% as CO_2 from fossil fuels (15). Fertilizer production has a large share in the classes of acidification, depletion of non-living resources, toxicity for aquatic animals and toxicity for marine aquatic animals (10). Direct nitrogen emissions usually occur during the agricultural production stage. Nitrogen emissions include the release of ammonia (NH_3) by sublimation, the release of nitrous oxide (N_2O) and nitrate leaching (NO_3). It is often difficult to estimate the true and accurate release of nitrogen into the aquatic environment because it is highly dependent on the soil type, climatic conditions and agricultural management operations. Measuring these emissions requires a lot of time and money, showing a lot of variability in any case (16). For this purpose, the average potential emission rate is determined according to the current conditions prevailing in the system under review. Therefore, methods are needed to facilitate the calculation of potential nitrogen emissions of each location (14). In this study, the standard methods (14) and environmental protection agency (EPA) (1995) were used to estimate nitrogen compounds (NH_3, N_2O and NO_3) used by the fertilizers. Nitrate is introduced into the soil by the fertilizers and mineralization by the microorganisms. Nitrate in the soil can be absorbed by the plants. The risk of nitrate leaching is higher in autumn and winter because in these seasons, the amount of rainfall is more than the amount of absorption by the plant. In addition, mineralization of nitrogen has the highest rate in late summer because at this time, nitrogen is slightly absorbed by the plant (17). Nitrate leaching wastes the plant's nitrogen, toxicity and atrophy and releases it into the air. Phosphorus leaching was calculated based on the equations proposed in the literature (5).

Ammonia Sublimation

The amount of ammonia sublimation in the mineral and organic fertilizers varies depending on the climatic conditions, soil characteristics, method and timing of fertilization. Among the mineral fertilizers, nitrogen has the most progressive acidification of ammonia in the soil. Herein, the emission factor of ammonia from nitrogen was considered due to the lack of necessary studies equivalent to the European average.

Prerequisites for calculating the ammonia emission include:

- Fertilization time: In this study, the time of fertilization was equal to 10-15. C
- Infiltration speed
- Low (solid animal manure)
- Precipitation after fertilization: There was no rain.
- Combination of fertilizer with the soil: Livestock manure and some chemical fertilizers were mixed with the soil before planting.
- Time between fertilization and mixing
- The time between emptying the manure and mixing was equal to one day.

N_2O Emission

Agriculture sector accounts for 47% of the world's nitrogen oxide emissions. Nearly 80% of N_2O emissions are related to the mineral and organic fertilizers. The 2 processes of nitrification and denitrification in the soil react to this diffusion.

Denitrification (N_2 N_2O NO NO_3 NO_2)

Nitrification (NH_4 N_2O NO_3)

Calculation of N2O emissions following Eqn. (18):

N_2O emission [kg N_2O-N × ha-1] = 0.0125 × N application [kg N × ha-1]……………………………..(Eqn. 18)

Nitrate (NO_3) Emission

Nitrate is one of the elements that can be highly absorbed by the plants and if not absorbed by the plant, it has a high leaching ability. According to the estimates (18), on average and according to the conditions, 14% of the used fertilizer is available as nitrate.

Phosphorus Leaching

Phosphate leaching usually takes place in the form of surface runoff and soil erosion, depending on the factors, such as soil type, amount of the used fertilizer, and soil erosion rate.

Leaching by the Surface Runoff (Eqn. (2)) (Eqn. (3)

Pro = Prol × Fro ……………………………………..(Eqn. 2)

Fro = 1 + 0.2 / 80 × P_2O_5min + 0.7 / 80 × P_2O_5sl + 0.4 / 80 × P_2O_5man…………………..……………………..(Eqn. 3)

Pro = The amount of phosphate lost by the runoff

Prol = Average amount of phosphate lost in arable land (0.175 kg of phosphate per hectare)

Fro = Fertilizer-related factors

Min = Mineral, sl = Soluble or aqueous, Man = animal manure

Leaching by the Soil Erosion

Per = The amount of eroded fossilized phosphate

Ser = The amount of eroded soil (kg per hectare)

Pcs = Phosphate content at high soil levels (0.00095 k)

Pesticides

The variety of the used pesticides, as well as the amount of their use in intensive cultivation was higher than the healthy cultivation. According to one method for quantification of the amount of pesticides propagated in the environment (19), 30-50% of pesticides are released into the air. Factors for calculating the spread of pesticides include the type of pesticide, environmental conditions, method of use and the applied skill (19, 20). Spraying and sublimation after that are the main causes for spread of pesticides in the air.

Electricity

In the present study, farmers used the electricity to pump the water for irrigation. The use of electricity is actually accompanied by the environmental effects.

Diesel Fuel

Diesel fuel consumption in the tractor engines and other related machinery leads to releasing some harmful compounds into the air. Emission factors for diesel fuel consumption have been provided by the intergovernmental panel on climate change (IPCC) (1996) (10). For each kg of diesel fuel, 0.1 g of N_2O, 0.2 g of CH_4, 3140 g of CO_2, 36 g of CO and 42 g of NO_X are released into the air (10).

Evaluating the Effect and Classes of the Studied Effect

At this stage, first, it is necessary to determine which classes of effects are considered and how to evaluate the effect (21). In this study, all 10 classes of effects in the method were discussed. These 10 classes of effects included depletion of non-living resources, acidification potential, swamp potential, global warming potential, ozone depletion potential, toxicity potential for human, freshwater toxicity potential and marine aquaculture toxicity potential. The toxicity potential for the terrestrial ecosystems was considered for formation of chemical oxides to determine the effects.

The environmental impact assessment was calculated with the ReCiPe impact assessment method version 1.03, a hierarchical (H) perspective, along with the cumulative energy demand method v1.11.

The SimaPro Software

In this study, SimaPro 8.0.4.30 software was used to evaluate the parameters. It is one of the most valuable and comprehensive softwares that includes a variety of methods for assessing the effects that are used to calculate the related consequences. In each method, specific environmental factors were evaluated. SimaPro software is used as a professional tool in analyzing the environmental aspects of goods or services. The software analyzes both systematically and permanently so that, the best solutions can be obtained for the project. SimaPro software has several versions and includes various information and methods for evaluating the effects. The software makes it possible to create the models for the products (goods and services) (22).

Herein, the SimaPro software version 8.0.4.30 was used, with 59 methods for evaluating the effects. Of these, 14 methods were collected including IMPACT 2002+ from European countries, 2 methods (BEES and 2 ACTR) from North America and several other methods including CML 2001. The software has a large number of projects. A project includes all the information that the user enters in its various sections including data collection, production steps of the product and information on impact assessment. Projects have been compiled based on the different countries with their own emissions.

Results and Discussion

Abiotic Depletion

Regarding the effects of depletion of unnatural resources related to rapeseed production at least related to its rape, as shown in Fig. 3, electrical energy of diesel fuel had the highest effect on rapeseed production. According to Fig. 3, in this area, 361.1 kg of CO_2 eq greenhouse gases are emitted to the atmosphere to produce one ton of product (6).

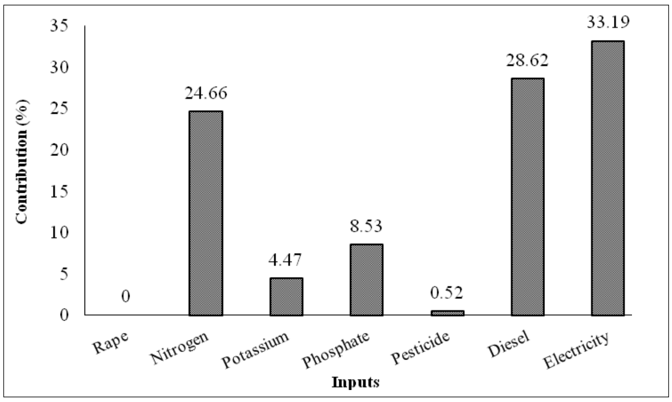

Fig. 3. The relative contribution of inputs to the abiotic depletion (kg Sb eq) in rapeseed production.

Acidification Index

It was found that the highest effect was related to the production of rapeseed and nitrogen fertilizer and phosphate fertilizer and sugar drop ranked second and third (Fig. 4).

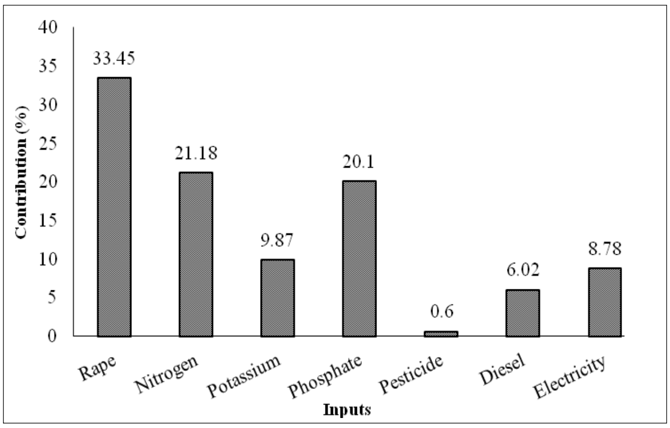

Fig. 4. The relative contribution of inputs to the acidification potential (kg SO_2 eq) in rapeseed production.

Eutrophication

According to the results, the highest share was related to rapeseed production and the least share was related to pesticides. Phosphate fertilizers and pesticides ranked the second and third (Fig. 5). Eutrophication in the surface water can cause algae growth leading to the loss of life in the ponds and lakes (23, 24). Most of potassium fertilizers have the least effect on eutrophication index and other indexes due to the optimal consumption on the farms. According to Fig. 5, triple super phosphate and nitrogen fertilizers had the greatest effect on air pollution in the cultivation of oilseed in the region. As per one report, the emissions of ammonia from agricultural activities and the emissions from nitrogen and potassium sulfate fertilizers for olive production had the highest share of 70.36, 18.42 and 5.63% respectively (25). In fact, the use of nitrogen and manure is the main reason for the high ammonia emissions. The use of nitrogen fertilizers leads to NO_3 emission to the soil and N_2O, NH_3 and NO_X into the atmosphere. Various influencing factors in the level of emission include the fertilizer, fertilization method, fertilization time, the amount of fertilizer used in the soil and weather conditions (25, 26).

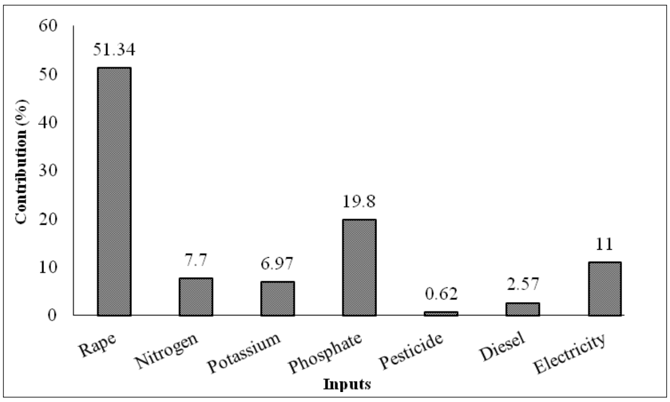

Fig. 5. The relative contribution of inputs to the eutrophication potential (kg PO_4 eq.) in rapeseed production.

Global Warming

Regarding the global warming index, the greatest effect was related to the production of rapeseed and the least effect was related to pesticides. Electrical energy and fertilizers were in second and third places (Fig. 6). Phosphate pesticides and fertilizers were in second and third places. It was showed that di-nitrogen oxide and carbon dioxide emitted by the fertilizers and diesel fuels had the greatest effect on the global warming potential (5).

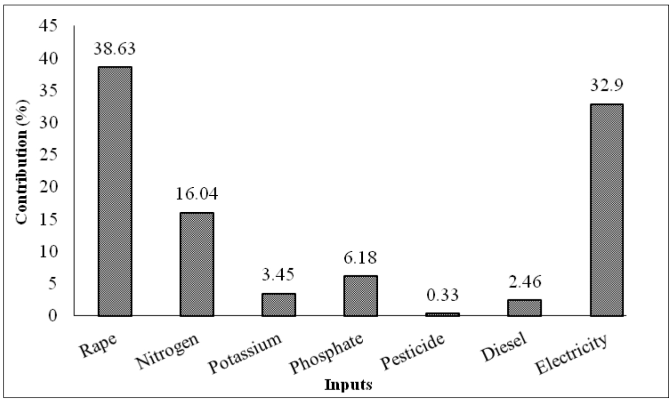

Fig. 6. The relative contribution of inputs to the global warming potential (kg CO_2 eq.) in rapeseed production.

Ozone Layer Depletion

Regarding the index of ozone layer gap, the highest effects were related to diesel fuel and electrical energy and the least correlated effects were related to potassium and nitrogen fertilizers. It also shows, the insecticide input with 82% of level had the greatest effect on the ozone layer depletion (Fig. 7). Among different types of pesticides, insecticides having toxic organic substances are being widely used. In this material, breaking of carbon bonds into chlorine is complex and the presence of chlorine reduces the reactivity of other bonds in the organic molecules. This means that by entrance of the chlorinated organic compounds to the environment, their degradation becomes slow and they would be more inclined to snuggle and that is why they have become a serious environmental problem. Toxicity potential for the humans was about 50.49 kg eq. 1.4-DB (Paradichlorobenzene) for one ton of rapeseed. The highest share of environmental pollution indicator was allocated to the insecticides and phosphate fertilizers. Generally, 68% of the share of this indicator was caused by applying the chemical fertilizers in the field.

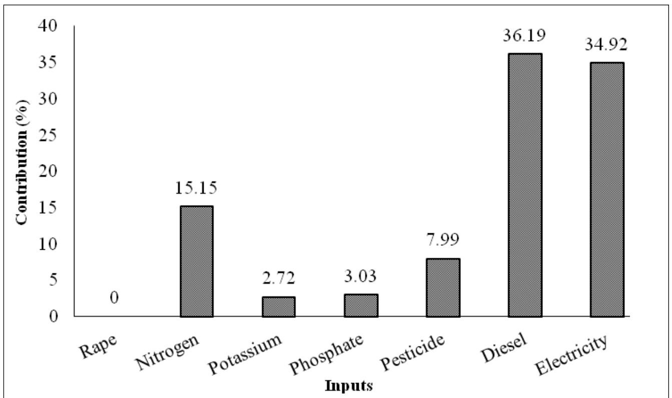

Fig. 7. The relative contribution of inputs to the ozone layer depletion potential (kg CFC-11 eq.) in rapeseed production.

Cultivation of winter rapeseed has a lower environmental impact than cultivation of spring rapeseed due to higher agricultural inputs and higher yield. The greatest impact is on human health. Mineral fertilizers (production and application) and agricultural machinery are responsible for the greatest environmental impact. The results for the mill stage of rapeseed oil demonstrated that the choice of the allocation method has a significant impact on the environmental performance results (1).

Conclusion

It was revealed that indirect energy uses from fertilizer consumption for crop growth made the greatest contribution in rice and wheat production systems with average values of 69.5% and 75.4% respectively of the total energy (27). The use of fertilizers and chemical pesticides, fossil fuels, management of agricultural soils, management of livestock manure and burning of organic waste are the most important sources of N2O production in the agricultural sector (28-30). According to the above-mentioned factors, chemical fertilizers had the greatest effect on the emissions of environmental pollutants. Our results showed that, generally, phosphate and nitrogen fertilizers and chemical pesticides were the most effective indicators of global warming, lake strangulation, acidification potential, ozone layer depletion and reduced organic sources. The amount of emission of the greenhouse gases was equal to 361.1 kg of carbon dioxide equivalent for the rapeseed. It was also revealed that the chemical fertilizer had the highest share among the evaluated inputs within the growth period. For production of one ton of rapeseed, 11.5 and 4.83 kg of N_2O and NO_X were released to the environment, which was associated with the eutrophication effects. Failure to properly manage the distribution and application of the agricultural inputs has caused the surface waters to be more toxic and be subjected to higher risk compared to other indicators. Investigations and evidences indicate that for production of one ton of rapeseed in Alborz province, the most environmental effects are related to global warming and eutrophication.

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Authors contributions

SKB Collected the data (field and lab works), data analysis, writing the article. MRA performed the research concept and design, field works, writing the article, critical revision of the article and final approval of the article. AMD and AHSR contributed to research conception and design, statistical analysis, writing the article. PNM contributed to research conception and design, lab work.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no competing interests.

Ethical issues: None.

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