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Research Paper

Environmental Life Cycle Assessment of Olive Fruit Production under Different Orchard Size and Upon Organic and Conventional Agro-Systems

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Abstract

The aim of this study was to investigate the environmental impacts of olive fruit production under different orchard size and upon organic and common agro-systems through Life Cycle Assessment (LCA) methodology in northern Iran. The data were collected using a self-made questionnaire and face-to-face interview with 305 olive growers in the study region. Six environmental impact categories (IC) including depletion of fossil fuels, global warming, acidification, terrestrial eutrophication, depletion of phosphate and potash resources have been investigated. One tone of olive fruit was set as the functional unit (FU). Results showed that the large olive orchards (≥5ha) had the highest negative environmental impacts in all studied IC. Overall, acidification, terrestrial eutrophication, and depletion of phosphate resources have been identified as the most important environmental challenges of olive fruit production with final indices of 1.58, 2.68, and 3.12, respectively. The results also revealed that the organic olive orchards are more environmental efficient than those of conventional orchards. Substituting a certain portion of chemical fertilizers used in the large olive orchards with the biological alternatives such as farmyard manure has been suggested to provide the nutritional requirements of olive trees. A regional strategy should be also planned to move to an appropriate integrated farming system to cut down the environmental hazards of olive fruit production in large orchards in the studied region.

Keywords:
Agriculture;
agro-ecosystems;
environmental impacts;
sustainability

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INTRODUCTION

Recently, the environmental impacts of agricultural production systems are carefully focused by the governments and organizations. Emission of pollutants to the natural resources of air, water, and soil are among the main challenges of agricultural sector. Moreover, sustainable use of the limited natural sources to provide production inputs of agro-systems is of highly important (Ziaabadi & Zare Mehrjerdi, 2019). Therefore, many countries started to assess the environmental sustainability of the agro-food systems using different tools to find the systems' hotspots and the most appropriate system options. Among them, life cycle assessment (LCA) methodology has been widely used as the most perfect tool to measure the environmental sustainability of agricultural processes and products. In this regard, a series of LCA researches were planned to assess environmental impacts of various agro-systems in Guilan Province, northern Iran as the main agricultural area of the country facing serious environmental threats. Nikkhah et al. (2015) identified the depletion of fossil fuel resources as the most important environmental hotspot of peanut cultivation agro-system in Guilan Province, northern Iran using LCA procedure. Small farms (≤0.5 ha) have been determined as the major contributor to the fossil fuel resource depletion in peanut production system. Firouzi et al. (2018) evaluated and compared the negative environmental impacts of rice production in single-cropping and ratooning agro-systems through LCA methodology in Guilan Province, Northern Iran. One hundred kg protein was set as the functional unit for the study. The terrestrial eutrophication followed by the depletion of phosphate resources ranked as the environmental hotspots of rice single-cropping agro-system. Also, the terrestrial eutrophication followed by the acidification were determined to be the most important impact categories in rice ratooning agro-system. Final results indicated that the rice ratooning ago-system had less negative environmental impact than the single-cropping agro-system. Environmental performance of tea production system has been studied by Nikkhah et al. (2017) through LCA approach in Guilan Province, Iran. Depletion of fossil resources category has been determined to be the most important environmental category for tea production system. Environmental index and resource depletion index have been calculated as 0.97 and 2.62, respectively.

Table 1 also shows the summary of the literature on the LCA of fruit production systems and the corresponding hotspots and remarks.

Table olive and olive oil are among major agricultural products in Rudbar County, Guilan Province. Rudbar County is known as the second olive producer in the country and it plays a major role to provide domestic need to olive products. Review of the related reports showed that there is no data about the environmental impacts of olive production in this region. The largest share of greenhouse gas emissions in olive oil production sector has been reported to be associated with the fruit production stage in the garden (Rajaeifar et al., 2014). Therefore, the study of environmental impacts of olive fruit production is an essential to mitigate the environmental problems of Guilan Province, Iran. In this regard, the effects of orchard size and method of production (organic and common farming systems) have been considered as the variables for the study of the environmental burdens of olive fruit production in Rudbar region, northern Iran.

METHODOLOGY

This study was conducted in Rudbar County, Guilan Province, northern Iran. Rudbar is the second largest olive producer in Iran (Figure 1). The life cycle assessment (LCA) methodology was used to assess the environmental impacts of olive fruit production in the study region. This procedure is based on the ISO 14040 standard framework (Figure 2). It is a reliable technique for measuring the environmental impacts of agro-food systems and to detect the hotspots and the most eco-friendly system options (Romeiko, 2019 & Hung et al., 2020). According to the ISO standard framework, LCA includes four sections including a) the definition of goals, b) analysis of inputs and outputs, c) impact assessment, and d) interpretation of impacts, which will be described in more detail below.

Table 1
Summary of the Literature on the LCA of Fruit Production Systems

Fruits	Number of studied orchards	Functional unit	Environmental hotspot	Remarks	Authors
Apple	64, 424, 24 orchards for conventional, integrated and organic farms, respectively	1 tonne apple	Higher impacts of younger apple trees in organic orchards	Low and high productive years in conventional, integrated and organic farms	Goossens et al. (2017)
Pistachio, almond and apple	10, 10, and 8, respectively	1 tonne fruit	Fertilizers production, irrigation system and field management	Comparative lca of fruits in Greece	Bartzas et al. (2017)
Strawberry	-	1 kilo Joule fruit	Plastics, fuels and fertilizers	strawberry production	Tabatabaie & Murthy (2016)
Pear	-	1 tonne pear	Mechanical cultivation and traditional storage systems	Conventional and organic pear production systems	Liu et al. (2010)
Kiwifruit	84	1 tonne kiwifruit	Nitrogen fertilizer	Kiwifruit production	Nikkhah et al. (2016)
Citrus	-	1 tonne citrus	Production Phase	Citrus production	Lo Giudice et al. (2013)
Grape	58	1 tonne grape	Poultry Manure	Grape production	Mohseni et al. (2018)

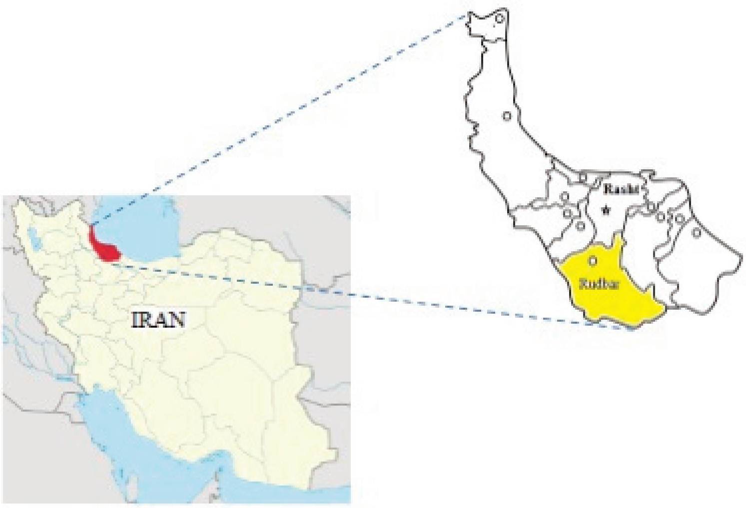

Figure 1. Map of the study area (Rudbar County, Guilan Province, Iran)

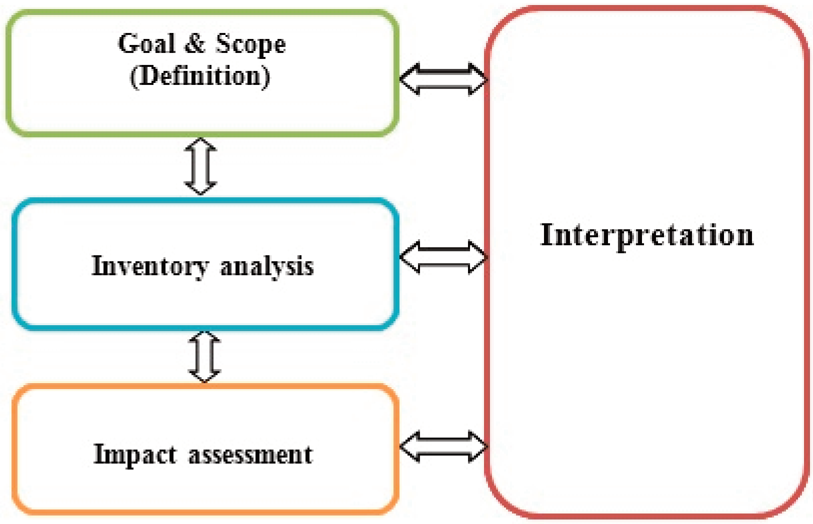

Figure 2. International Standard ISO 14040 framework for the LCA study (ISO, 2006)

Goals and scope definition

In order to evaluate the environmental impacts of olive fruit production, 1 tonne of olive fruit was considered as the functional unit of the study. The environmental performance was investigated in terms of impact categories of global warming, acidification, eutrophication, depletion of fossil fuels, phosphate, and potassium resources per 1 tonne of olive fruit.

Inventory analysis

Figure 3 shows all activities responsible to various environmental impacts for olive fruit production agro-system; including background and foreground practices. Mostly, in the LCA studies of agricultural sector of Iran, environmental emissions from consumption of the four main production inputs including various chemical fertilizers (nitrogen, phosphate and potash) and fossil fuels (diesel and gasoline) have been considered (Firouzi et al., 2017; Firouzi et al., 2018; Mohammadi-Barsari et al., 2016; Nikkhah et al., 2015; Nikkhah et al., 2016). The data were collected using a self-structured questionnaire and face-to-face interview with 305 olive orchardists in Rudbar region, Guilan Province, Iran. Sample size was determined using Cochran's formula (Snedecor & Cochran, 1980).

$$n = \frac{N(s \times t)^2}{(N-1) \times d^2 + (s \times t)^2}$$

$$d = \frac{t \times s}{\sqrt{n}}$$

where n is the sample size; s, the standard deviation; t, the value at 95 percent confidence interval (1.96); N, the number of holding in target population and d, the acceptable error (permissible error 5 percent). For the calculation of sample size, criteria of 5 percent deviation from population mean and 95 percent confidence level were used.

The most important pollutants released into the environment including the CO_2, CH_4, N_2O, NOx, NH_3, and SO_2 were considered as the system output. The emission coefficients for each pollutant were derived from Brentrup et al. (2000) and Snyder et al. (2009).

Impact assessment

In this section of the LCA study, the impacts of all emissions including CO_2, CH_4, N_2O, NO_x, NH_3, and SO_2 were determined for the related impact categories. According to Table

2, each pollutant affects one or more groups. For example, the impacts of the CO_2, CH_4, and N_2O emissions on the critical global warming impact category are 1, 21 and 310, respectively. Therefore, N_2O contributes the most to the global warming. Also, NH_3 with a coefficient of 1.6 has the greatest impact on the acidification impact group. The values of the classification indices were calculated by multiplying the amount of each pollutant to the corresponding coefficient and then, summing them.

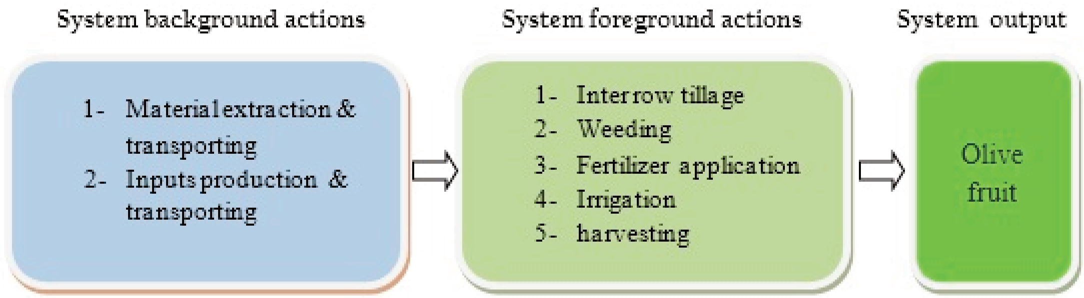

Figure 3. System background and foreground for olive fruit production in Rudbar Region, Guilan Province, Iran

Table 2

Potential of Each Pollutant on the Environment in Various Impact Categories in Rudbar Region, Iran

Impact category	Performance of each combination	References
Global warming	CO2=1, CH4=21, N2O=310	Snyder et al. (2009)
Acidification	SO2=1.2, NOX=0.5, NH3=1.6	Brentrup et al. (2004)
Terrestrial Eutrophication	NH3=4.4, NOX=1.2	Brentrup et al. (2004)
Depletion of fossil resources (MJ)	42.86	Brentrup et al. (2004)
Depletion of phosphate resources (kg)	0.25	Brentrup et al. (2004)
Depletion of potash resources (kg)	0.105	Brentrup et al. (2004)

Next, to compare the indices with each other, it is necessary to initialize each value by dividing it by the corresponding normalization factor, and then, its multiplying to the corresponding weighting indices (1.05, 1.8, 1.4, 1.14, 1.2, and 0.3 for the environmental impact groups of global warming, acidity, onshore eutrophication, depletion of fossil fuel sources, depletion of phosphate sources, and depletion of potassium sources, respectively.

Interpretation of the results

Effects of environmental impact groups of global warming, acidity, onshore eutrophication are visible in a shorter period of time while the impacts of fossil fuel, phosphate and potash resources depletion are among the challenge for the future and its effects are visible over a longer period of time.

Impact assessments were investigated for three olive garden size categories including small (≤1ha), medium (>1ha & ≤5ha), and large (>5ha) orchards. Moreover, the olive gardens were subdivided into two main categories of organic and common ones.

The analysis of variance (ANOVA) and a post-hoc analysis (Duncan test) to compare mean were used to examine the statistical differences between all environmental traits means in various orchard sizes, and in organic and conventional production agro-systems. All the environmental impacts calculations and charts drawing have been done using Excel 2013 software.

RESULTS AND DISCUSSION

The amounts of various inputs including different types of chemical fertilizers and fossil fuels at different levels of olive orchard size are shown in Table 3. According to the results, the amounts of fossil fuels consumed in large olive orchards (220.280 L gasoline and 375.08 L diesel $1000kg^{-1}$olivefruit) was significantly ($p \leq 0.01$) more than the small orchards (8.39 L gasoline and 2.42 L diesel $1000kg^{-1}$olivefruit) and medium orchards (48.30 L gasoline and 16.17 L diesel $1000kg^{-1}$ olivefruit). The increasing trend in the use of fossil fuels with the increase in the size of the gardens is related to their level of mechanization. Small gardens are often irregular shape of tree planting and then, cannot be mechanized. However, the planting pattern of olive trees in medium and large orchards is in regular order, which is suitable for the mechanization of olive fruit production. Although due to a lack of manpower, the mechanization of olive production in the olive orchards is inevitable, it is important to note that this amount of fossil fuel consumption is very significant. Determining the appropriate size of farm machinery in respect to farm size, renewing the existing farm tractors, and preventing from intensive tillage operation are among approaches to reduce fossil fuel use in large olive orchards. Furthermore, intensive tillage leads to decrease in soil carbon sequestration and then, increase in atmospheric CO_2 levels (Chatskikh & Olesen, 2007; West & Marland, 2007).

Also, the consumption of diesel and gasoline fuels in olive fruit production were 87.49 and 106.47 liters, respectively and in organic method were 13.96 and 11.94 liters per 1000 kg, respectively. As such, organic gardens consume far less fossil fuel than conventional gardens.

In large gardens (≥5 ha), phosphate and potash fertilizers usage are much more than the medium and small gardens. Therefore, managing these fertilizers in large gardens is essential. Replacing chemical phosphate with rock phosphate and use of farmyard manure are among approaches to reduce these chemicals and then, mitigate their environmental impacts in olive fruit production in the study region.

Table 4 shows the amounts of different pollutants emitted in various olive garden sizes. As seen, CO_2 has the greatest amount of mass in all gardens. However, each pollutant has its special effect in every environmental impact category. For instance, according to the Table 1, the coefficients of CO_2, CH_4, and N_2O to the global warming potential are 1, 21, and 310, respectively. This means that the effect of nitrogen dioxide is 310 times the effect of carbon dioxide on global warming potential impact category. Thus, more precise look to the environmental hazards of these emissions needs to determine the effects of the pollutants in the different environmental impact classifications. Table 3 also shows the emissions contributed to different impact categories.

According to Table 5, the large olive orchards (>5ha) had significantly wider negative environmental impacts against the small (≤1ha), and medium orchards in all impact categories. As seen in Table 3, a high consumption of various fossil fuels and chemical fertilizers in large orchards are responsible for this result. Moreover, the large olive orchards constitutes young trees with less yield, therefore, higher environmental impacts for 1 tonne of olive fruit as the study functional unit is justifiable. Implementing the right size of farm tractors and machinery,

Table 3

Amount of Different Inputs Consumed for 1 Tonne Olive Fruit at Different Orchard Sizes

Inputs		Olive orchards			Average
		Small (≤1ha)	Medium >1ha & ≤5ha	Large >5ha	
Fossil fuel(L 1000kg^{-1} fruit)	Gasoline	8.39	48.3	220.80	64.44
	Diesel oil	2.42	16.17	375.08	77.70
Chemical fertilizer(kg1000kg^{-1} fruit)	Nitrogen (N)	77.65	84.03	346.71	130.55
	Phosphate (P_2O_5)	32.25	41.62	264.92	79.57
	Potassium (K)	29.14	48.90	294.45	86.82

Table 4

Total Amounts of Various Pollutants Emitted in Different Olive Garden Size (EU: 1000 Kg Olive Fruit)

Emission resources	Pollutant	Amount of emissions (kg 1000 kg^{-1} olive fruit)			
		Small (≤1ha)	Medium (>1ha & ≤5ha)	Large >5ha	Average
Fossil fuel, Phosphate	CO_2	291.1	1408.06	27919.70	5912.27
Fossil fuel, Urea, Phosphate	CH_4	0.15	0.34	1.63	0.51
Fossil fuel, Urea	N_2O	3.15	5.85	79.66	18.56
Fossil fuel, Urea, Phosphate	NO_x	0.68	1.68	7.79	2.42
Fossil fuel, Urea, Phosphate	SO_2	0.42	0.75	3.99	1.22
Fossil fuel, Urea, Phosphate	NH_3	15.93	17.24	71.15	26.79

and renewing them are among the approaches to optimize the non-renewable production inputs in large olive orchards. Moreover, enhancing the chemical fertilizers use efficiency particularly for nitrogen fertilizer may leads to mitigate the related environmental impact categories. In this regard, timely application of a right amount of nitrogen fertilizer and replacing it with the biological alternatives are among useful approaches to diminish the related environmental impacts.

Table 5 also shows that there are a nil threats regarding the use of production inputs in acidification, terrestrial eutrophication, depletion of phosphate and potash resources categories in organic olive fruit production agro-system. These results can be justified by the no use of chemical fertilizers in organic agro-system. Tuomisto et al. (2012) reported a drop in nitrate leaching, eutrophication, and acidification in organic farming system, while an increase in land use per capita of crop yield. Table 5 also indicates less environmental impacts in organic olive production agro-system against the common agro-system in terms of fossil energy use and GHG emissions categories. A similar result has been reported by Liu et al. (2010) for pear fruit production in China. Nemecek et al. (2011) also stated the organic agro-system is better in land scale but the integrated cropping system prevails in crop-based functional unit. Therefore, researches on the effect of integrated farming system on the crop yield and then its environmental performance should be noticed by the regional agricultural office as an essential.

Table 5

Normalized Indices of Different Environmental Impact Categories of Olive Fruit Production under Different Garden Size in Rudbar Region, Iran

Garden size	Depletion of fossil resources (MJ)	Global warming	Acidification	Terrestrial Eutrophication	Depletion of phosphate resources (kg)	Depletion of potash resources (kg)
Small	0.01±0.00 [a]	0.16±0.03 [a]	0.51±0.09 [a]	1.13±0.19 [a]	1.05±0.31 [a]	0.38±0.09[a]
Medium	0.09±0.04 [b]	0.40±0.06 [b]	0.56±0.09 [a]	1.24±0.19 [a]	1.36±0.22 [a]	0.63±0.12 [a]
Large	0.76±0.26 [c]	6.47±1.77 [c]	2.36±0.94 [b]	5.12±2.07 [b]	8.65±4.60 [b]	3.80±2.27 [b]
Common	0.21±0.06 [a]	1.66±0.42 [a]	1.04±0.22	2.27±0.48	3.08±1.05	1.33±0.51
Organic	0.03±0.01 [b]	0.22±0.10 [b]	nil	nil	nil	nil
Total	0.18±0.05	1.43±0.36	0.88±0.19	1.92±0.41	2.60±1.04	1.12±0.43

Different letters indicate significant differences among mean values (p<0.05)

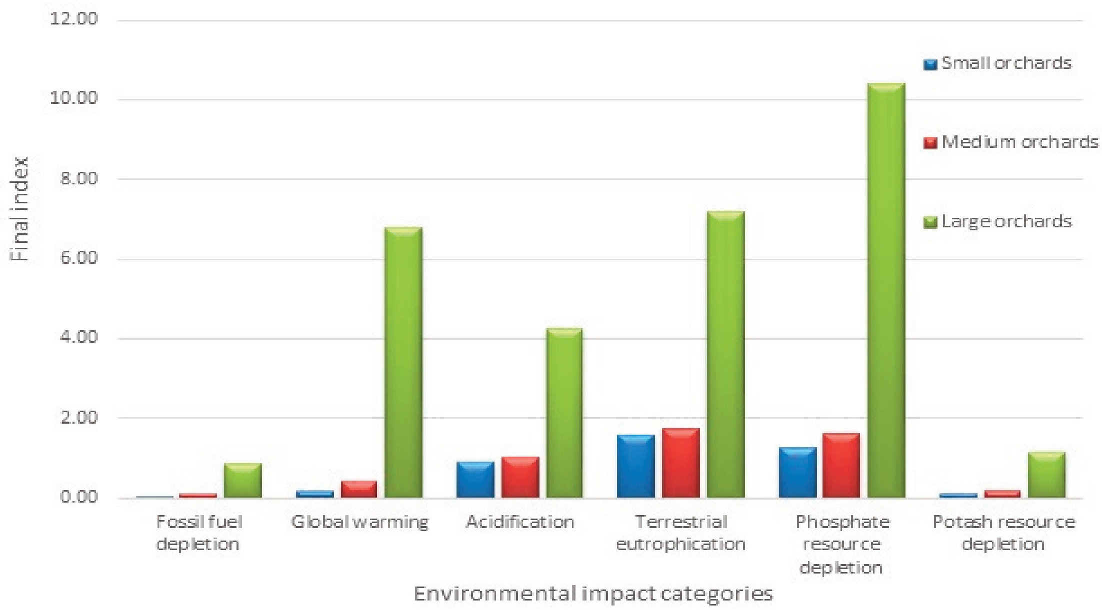

Figure 4. Means comparison of final indices of various impact categories of olive fruit production under different orchard size in Rudbar region, Guilan Province, Iran

According to Figure 4, phosphate resource depletion has been as the most important environmental category in large olive orchards, while the terrestrial eutrophication category has been the most environmental impact category in small and medium orchards. The final index of phosphate resource depletion in large orchards has been computed to be 10.38 against 1.26 and 1.63 in small and medium size olive orchards, respectively. Moreover, the final indices of the terrestrial eutrophication category for small and medium size orchards have been determined to be as 1.58 and 1.73, respectively, against a mean value of 7.16 for the large olive orchards. Therefore, reducing the NH_3 emission as on farm source of the terrestrial eutrophication through decrease in nitrogen chemical fertilizer usage should be seriously noticed by the regional small and medium size orchards olive growers. Furthermore, reducing the phosphate chemical fertilizer usage by using appropriate farmyard manures should be considered to mitigate the negative impact of phosphate resource depletion in large size olive orchards. In overall, Figure 4 shows that the large olive orchards had more negative environmental impacts in all categories; requiring more attention by the regional agricultural organizations.

Figure 5 shows the final indices of various impact categories of olive fruit production upon common and organic agro-systems in the study region. As seen, the global warming potential and fossil fuel depletion impact categories have been ranked as the first and second most important environmental burdens in organic olive fruit production agro-system, respectively, while, depletion of phosphate and potash resources have been determined to be as the first and second important impact categories in common agro-system. Overall, the environmental impacts of olive production in common agro-system are significantly more than the organic production agro-system. However, due to a significant decrease in fruit yield in organic agro-system, substituting

the common olive production system with a an appropriate integrated farming system to cut down a large portion of the environmental hazards of olive fruit production and at the same time, providing the economic benefits of the olive gardeners may be advised as an applied strategy in Rubar region, northern Iran.

CONCLUSION

The results of the study showed an overmuch consumption of non-renewable production inputs to produce unit mass of olive fruits in large orchards of Rudbar Region in

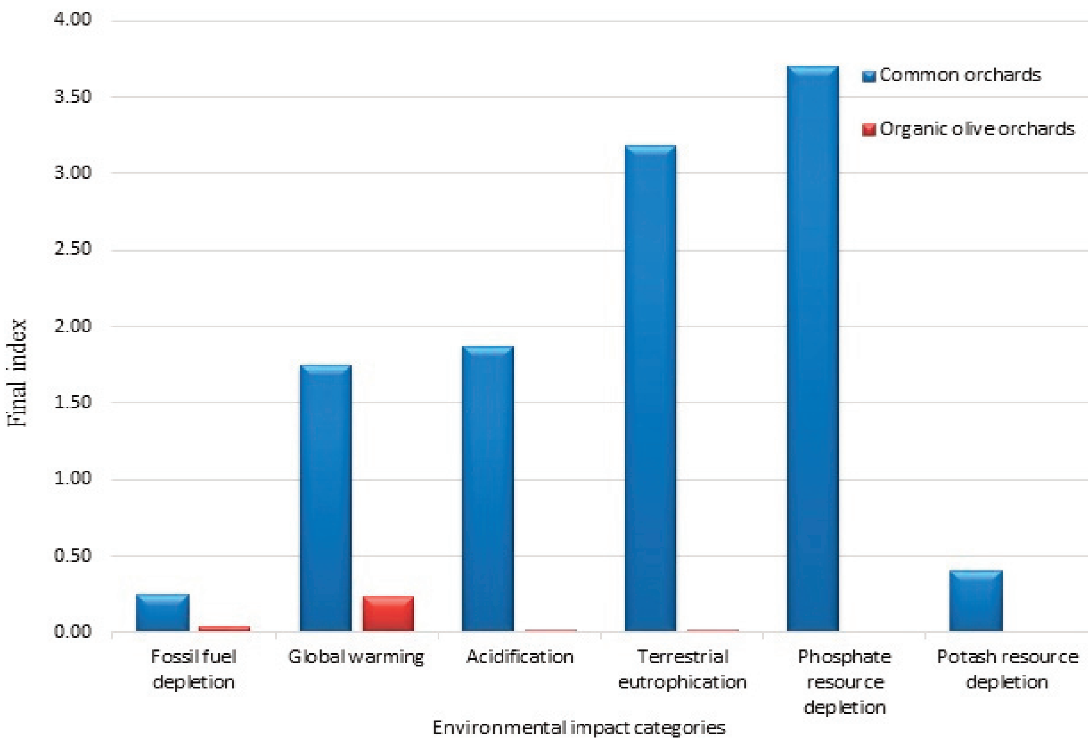

Figure 5. Means comparison of final indices of various impact categories of olive fruit production upon common and organic agro-systems in Rudbar region, Guilan Province, Iran

northern Iran. Therefore, improvement of chemical fertilizer use efficiency and replacing them with the appropriate biological alternatives, and managing the farm power usage in large olive orchards are essential. Totally, acidification, terrestrial eutrophication, and phosphate resource depletion have been identified as the most prevailing environmental impact categories in all orchard size groups. Organic olive fruit production showed better environmental performance than the common production system, but regarding to less fruit yield per unit area of crop land; it is suggested to promote the integrated farming system among olive growers in the study region.

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