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Could energy equilibrium and greenhouse gas emissions in agroecosystems play a key role in crop replacement? A case study in orange and kiwi orchards

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Abstract

The development of agriculture is linked to energy resources. Consequently, energy analysis in agroecosystems could be a useful tool for monitoring some measures in the agricultural sector to mitigate greenhouse gas emissions. The objectives of this study were to (a) evaluate differences of energy indices in orange and kiwi orchards, and (b) point out whether inputs, outputs, efficiency, productivity, and

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carbon footprint can play a key role in crop replacement. Proportional stratified random sampling was used to select 26 orchards (10 oranges, 16 kiwis) from the Prefecture of Arta, western Greece, during 2015 and 2016. Univariate statistical methods were combined with multivariate ones. Nitrogen, Mg, Zn, herbicides, insecticides, fungicides, renewable energy inputs, fruit production, total outputs, and energy efficiency and productivity were statistically significantly high in the orange orchards. Phosphorus, Ca, irrigation, machinery, total inputs, intensity, non-renewable energy consumption, and carbon footprint were statistically significantly high in the kiwi orchards. The most important energy inputs for both fruit crops were fertilizers, fuels, irrigation, machinery, and herbicides. The orange orchards seem to be more friendly to the environment than the kiwi orchards by having low total energy inputs 32,210.3 MJ ha^{-1}, intensity 1.4, consumption of non-renewable energy 0.7 MJ kg^{-1} and CO_2 equivalent/fruit production 0.08 kg kg^{-1}, and high energy outputs 105,120.0 MJ ha^{-1} and fruit production 53,648.0 kg ha^{-1}. The findings of the present study show a relation between climate change and the production of farming systems, which can be a tool for decision makers. The correlation of the abovementioned parameters ensure higher profits and could help in achieving the best possible sustainable management of the agricultural ecosystems.

Keywords: Agricultural practices, Carbon footprint, Energy analysis, Life cycle assessment, Mediterranean agriculture

Introduction

During the last 40 years, energy inputs of intensified agriculture increased by 137%, while land use increased less than 10% (Pellegrini and Fernández 2018). The development of agriculture is linked to energy resources. The increased food production due to the expanded demand led to intensification, a threat to the environment and the energy resources. Less intensive farming methods can minimize the risk of environmental effects (Tilman et al. 2002; Dantsis et al. 2010). Energy efficiency can prevent negative environmental issues and maintain energy resources. Agricultural practices that demand greater quantities of inputs (fuels, fertilizers, irrigation, electricity, insecticides, fungicides, herbicides, and machinery) are held responsible for the rise in energy usage and the accompanied elevated emissions of greenhouse gases (Kavargiris et al. 2009; Michos et al. 2012, 2018). Therefore, an increase in efficiency of the production systems is bounded with the effective use of energy resources and the emissions of greenhouse gases (Kaltsas et al. 2007; Taxidis et al. 2015; Michos et al. 2018). Energy balance determination could provide comprehensive information on the environmental impacts of different crop production technologies and management practices, such as greenhouse gas emissions (Lazaroiu et al. 2018). It could help adapt agricultural production and support the most efficient management of the different production coefficients (Elhag and Boteva 2019; Navaro Miro et al. 2019). Energy analysis is affected by the energy inputs and factors such as the location and the production period (Hülsbergen et al. 2001). Consequently, an energy analysis could offer input reduction, which is an environmental policy, while giving a boost to productivity (Michos et al. 2017; Unakitan and Aydin 2018).

Emissions of greenhouse gases are interlinked to energy inputs. The greenhouse gases (mainly CO_2, CH_4, and N_2O) have a negative impact on the climate. According to IPCC (2014), the agricultural sector accounts for 22% of the greenhouse gases, while cultivation practices account for 20% of the CO_2 yearly global emissions. The Paris Agreement for the climate demands a drastic reduction of energy inputs (e.g., fuels and fertilizers) and applied farming practices (Bryngelsson et al. 2016). Global and European agricultural policies encompass methods that aim to reduce fossil fuel use, while simultaneously maintain agricultural outputs (Alluvione et al. 2011). New methods and techniques are required to low greenhouse gas emissions down to 80–95% by 2050 (Adewale et al. 2018; Huang et al. 2019).

In Europe, orange (*Citrus sinensis* (L.) Osbeck.) and kiwi (*Actinidia deliciosa* L.) represent 8.4% and 23.3% of the global production, respectively (FAO 2017). In Greece, the orange and kiwi output per year is 0.96 and 0.27 Mt, respectively, and coincides with an orchard area of 29.6×10^3 (orange) and 9.2×10^3 (kiwi) ha (FAO 2017).

Greece is a Mediterranean region and it is expected that climate change will negatively affect crop production (IPCC 2014). The Mediterranean area is mainly considered an “environmental hotspot” (Espadas-Aldana et al. 2019). Therefore, it is important to enhance less intensive cultivations and farming practices to improve energy efficiency and reduce greenhouse gas emissions (Alonso and Guzmán 2010). Energy indicators and carbon footprint is a useful tool to achieve the Paris Convention climate targets and to decide the most environmental-friendly crop replacement. Policymakers and farmers can use the life cycle assessment (LCA) method to determine energy indices and greenhouse gas emissions (Taxidis et al. 2015; Michos et al. 2018).

Climatic changes affect the life cycle of crops and their production cost (Lichtfouse 2011). In Greece, local mid-early orange varieties cultivated at Prefectures Arta and Chania dominated the national orange production in the past. They were later replaced by imported varieties “Navel” and “Valencia” with high fruit production (Minagric 2007). In the Prefecture of Arta, the imported orange varieties had not only high fruit production but high energy inputs as well, leading to high production cost. A result of this was the farmers’ willingness to continue with orange cultivation. The rising sell price of kiwi fruit, which can be produced in the region, has led many farmers to abandon oranges and turn to kiwi cultivation. These alterations should take into account the effects on the environment and ensure not only higher profits but the best possible sustainable management of the agricultural ecosystem as well. According to Nabavi-Pelesaraei et al. (2014a, b), the most critical inputs effecting Tangerine production are fertilizers, pesticides, and diesel fuel. Diesel fuel and nitrogen fertilizer are some of the most sensitive inputs for kiwifruit yield and greenhouse gas emissions (Nabavi-Pelesaraei et al. 2016). Mostahari-Rad et al. (2019, 2021) stated that citrus production had lower gas emissions than hazelnut and kiwi. New practices should be adopted to reduce nitrogen fertilizer consumption, utilizing more non-renewable energy and reduce fuel consumption to enhance climate change mitigation and adaptation in agricultural production (Nabavi-Pelesaraei and Amid 2014; Nabavi-Pelesaraei et al. 2016; Michos et al. 2018, Kaab et al. 2019; Ghasemi-Mobtaker et al. 2020).

Given the importance of monitoring sustainable agricultural production (Bracco et al. 2019), it is essential to create and apply indicators to assess and evaluate sustainable agricultural production performance. According to the EC (2020), an environmental impact assessment should include the energy use and the greenhouse gas emissions during agricultural production. In addition, European Union’s goals are to reduce the environmental and climate footprint of the EU food system and enhance sustainable food production (EC 2020). The objectives of this study were to (a) evaluate differences of energy indices in kiwi and orange orchards, and (b) point out whether energy inputs, outputs, efficiency, productivity, and carbon footprint can play a key role in crop replacement.

Figure 1 Map of Greece with the selected orange (O) and kiwi (K) orchards in Arta Prefecture

Materials and methods

Orchards and site information

During the years 2015 and 2016, 10 orange and 16 kiwi orchards were chosen in Arta Prefecture, western Greece. The studied orange orchards with a total of 19.0 ha out of 204.6 ha of the study area (9.3%) and the kiwi orchards with a total of 28.8 ha out of 233.5 ha of the study area (12.3%) were located at the southern part of the Prefecture, near Amvrakikos Gulf. Proportional stratified random sampling was used to select the studied orchards (**Figure 1**). The two fruit crops (orange and kiwi) were considered as the strata of the sample scheme. The studied orchards were sampled from the local cooperative directory (catalogue) taking into account that about 10% of the total area of the two fruit crops should be represented into the sample (Michos et al. 2017), as described above. Orange orchards had an average size of 1.9 ha and an average age of about 26 years. Kiwi orchards had an average size of 1.8 ha and an age of about 11 years. The studied fruit crops were at their highest production. The altitude of the orange orchards was from 3 to 10 m and the variety was cv. "Navel." The kiwi orchards altitude was from 4 to 30 m and the variety was cv. "Hayward." There were 250–370 trees per ha in the orange orchards and 364–667 vines per ha in the kiwi ones. The owners of these orchards were occupied with their cultivation for more than 15 years. The mean annual precipitation, temperature, and relative humidity (mean ± SD; $n = 15$ years) were 118 ± 65 mm, 19 ± 5 °C, and 67 ± 7%, respectively, in the study area (Greek National Meteorological Service).

Life cycle assessment

Several research papers have been carried out either applying environmental impact assessment methods for the life cycle of agricultural production (Michos et al. 2018; Espadas-Aldana et al. 2019; Litskas et al. 2019; Gkisakis et al. 2020), or categorizing and analyzing assessment methods (Schader et al., 2014). In the present study, an adjusted to agriculture life cycle assessment (LCA) method (**Figure 2**), involving five stages, was used to determine energy inputs, outputs, and emissions of greenhouse gases (ISO 2006a, b; Finnveden et al. 2009; Zafiriou et al. 2012; Taxidis et al. 2015; Adewale et al. 2016; Litskas et al. 2017, 2019; Michos et al. 2018; Platis et al. 2019).

Energy content

Table 1 presents the management practices of the orchards during 2015 and 2016. The farmers' work-plan, each activity's duration, the used machines and laborers, the irrigation method, and the amount of the fuels, pesticides, and fertilizers applied were used to estimate the energy inputs. This energy includes the used material, the fuel consumption, and each operation's duration. The embodied energy of the machinery was estimated using the related coefficient indices (**Table 2**). Most of the machinery used in the studied farms were more than 20 years old. For this reason, the coefficients have been adapted to reflect the status of the machinery structure, materials, use, repairs, cost of

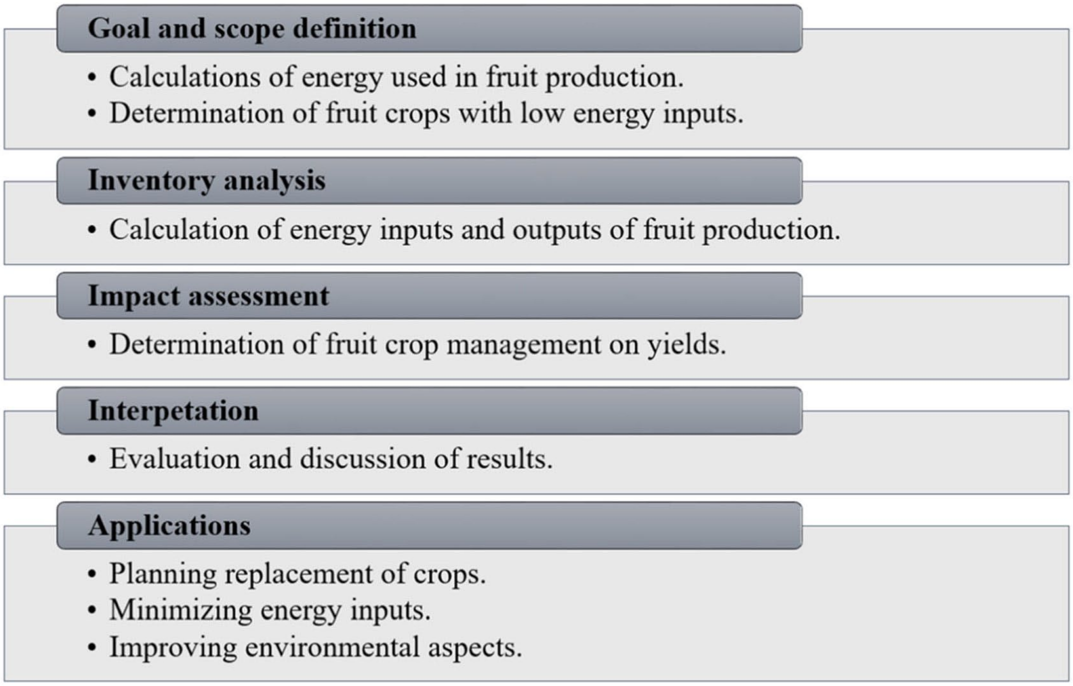

Figure 2 A life cycle assessment (LCA; adjusted) with five stages

maintenance practices, and working conditions. The embodied energy of the machinery structure materials derives from the energy for manufacture (86.40 MJ kg^{-1} of mass; Pimentel et al. 1973), the energy for repairs and maintenance (0.55 times the manufacture energy; Fluck 1985, 1992), and the energy for transportation (8.80 MJ kg^{-1}; Bridges and Smith 1979). The total embodied energy for each machinery used for the first time is the product of 142.7 MJ kg^{-1} [86.40 MJ kg^{-1} of mass + (0.55 × 86.40 MJ kg^{-1} of mass) + 8.80 MJ kg^{-1}] times the weight machinery. The duration of the machinery life is from 2,000 to 15,000 h. An amount of energy is lost per hour of the machinery total life. This amount equals to the ratio of the total embodied energy divided by its total life. The loss of the initial embodied energy is affected by the working hours of the machinery. The required energy for each operation is the sum of the embodied energy and the energy of fuel and human labor (Table 2). Total energy inputs include renewable energy (animal manure, human labor) and non-renewable inputs (chemical fertilizers, pesticides, and fuels).

Table 1 Farming practices for the selected orange and kiwi orchards

Agricultural practices	*Orange*	*Kiwi*
Fertilizer application	Patentkali (30% K_2O, 10% MgO, 42.5% SO_3 Mg ha^{-1}, 3 ± 1 Mg ha^{-1}) and fertilizers with different composition (12% N, 8% P_2O_5, 16%K_2O; 1 ± 0.2 Mg ha^{-1} or 11% N, 15%P_2O_5, 15%K_2O; 0.9 ± 0.1 Mg ha^{-1} or 20% N, 20%P_2O_5, 20%K_2O; 1.2 ± 0.2 Mg ha^{-1}). The fertilizers are applied 2 or 4 times year^{-1}.	Complesal (12% N, 8% P_2O_5, 16%K_2O, 3% MgO, 10% S, 0.02% B, 0.06% Fe, 0.01% Zn; 0.9 ± 0.3Mg ha^{-1}) and fertilizers with different composition (12% N, 8% P_2O_5, 16%K_2O; 0.8 ± 0.2 Mg ha^{-1} or 11% N, 15% P_2O_5, 15%K_2O; 0.75 ± 0.1 Mg ha^{-1} or 20% N, 20% P_2O_5, 20% K_2O; 0.9 ± 0.2 Mg ha^{-1} or 15.5% N, 18% Ca; 0.3 ± 0.2 Mg ha^{-1} or 21% N; 0.3 ± 0.2 Mg ha^{-1} or 11% N, 7% P_2O_5, 14%K_2O; 0.8 ± 0.1 Mg ha^{-1}). The fertilizers are applied 1 to 3 times year^{-1}.
Weed control	Farmers are cutting weeds (3–5 times year^{-1}) by using machinery (lawn mower) or by hand.	Farmers are cutting weeds (4–6 times year^{-1}) by using machinery (lawn mower).
Fungicides	Farmers apply (2 times year^{-1}) quantities of copper hydroxide, which range from 0 to 0.8 kg ha^{-1} totally.	Farmers apply (2–4 times year^{-1}) quantities of Bordeaux mixture, copper hydroxide, and Mancozeb, which range from 0.3 to 5.8 kg ha^{-1} totally.
Insecticides	Farmers apply (1–2 times year^{-1}) quantities of paraffinic mineral oil, pyrethrins, which range from 0.8 to 3.0 kg ha^{-1} totally.	Farmers apply (1–2 times year^{-1}) quantities of imidacloprid and pyriproxyfon, which range from 1.5 to 1.8 kg ha^{-1} totally.
Pruning	One or 2 times year^{-1} (November to December, June to August) with aero-scissors	Two times year^{-1} (November to December, June to August) with aero-scissors
Irrigation	From April to June 7–17 times with sprinkler heads functioning	Same practices
Fruit thinning	From April to June by hand	Same practices
Harvesting	During the October and November by hand	Same practices

Table 2 Energy content of inputs

Item	*Unit*	*Content energy (MJ/unit)*	*Mass (kg)*	*Life (h)*	*References*
Fertilizer					
Nitrogen (N)	kg	74.2			Lockeretz (1980); Tsatsarelis (1993)
Phosphorus (P)	kg	13.7			Lockeretz (1980); Tsatsarelis (1993)
Potassium (K)	kg	9.7			Lockeretz (1980); Tsatsarelis (1993)
Calcium (Ca)	kg	8.8			Pimentel (1980)
Magnesium (Mg)	kg	8.8			Pimentel (1980)
Zink (Zn)	kg	8.4			Pimentel (1980)
Sulfur (S)	kg	3.0			Mudahar and Hignett (1987)
Cupper (Cu)	kg	13.3			Pimentel (1980)
Agrobiozol	kg	6.5			Kavargiris et al. (2009)
Patenkali	kg	6.0			Kaltsas et al. (2007)
Sheep and goat manure	kg	23.5			Makhijani and Poole 1975)
Insecticides	kg	363.6			Kaltsas et al. (2007)
Microbial insecticides	kg	290.0			Kaltsas (2005)
Paraffin	l	46.0			Tsatsarelis (2011)
Fungicides	kg	99.0			Kaltsas et al. (2007)
Herbicides	kg	418			Kavargiris et al. (2009)
Petroleum (diesel)[a]	l	47.3			Cervinka (1980)
Electric energy	kWh	12.1			Jarach (1985)
Machinery					
Tractor 48kw	h	41.4	4350	15000	Tsatsarelis (1992) adapted
Pump	h	2.4	200	12000	Tsatsarelis (1992) adapted
Fertilizer distributor	h	5.7	100	2500	Tsatsarelis and Koundouras (1994) adapted
Manure distributor	h	14.28	100	2500	Tsatsarelis and Koundouras (1994) adapted
Branch destroyer	h	17.7	300	2500	Tsatsarelis and Koundouras (1994) adapted
Irrigation system	h.m	0.092	--	15000	Tsatsarelis (1992) adapted
Field cultivator	h	17.1	300	2500	Tsatsarelis (1991) adapted
Rotary tiller	h	17.7	310	2500	Tsatsarelis and Koundouras (1994) adapted
Sprayer	h	19.1	200	1500	Tsatsarelis and Koundouras (1994) adapted
Lawn mower	h	1	10	1500	Tsatsarelis (1993) adapted
Transportation	h	48.9	1500	15000	Genitsariotis et al. (1996, 2000) adapted
Platform	h	57.1	1000	15000	Tsatsarelis (1992) adapted
Insect traps	h	0.002	0.3	18000	Tsatsarelis (1993) adapted
Tank 0.5 Mg	h	14.3			Kaltsas et al. (2007) adapted
Tank 1.0 Mg	h	23.8			Kaltsas et al. (2007) adapted
Tank 2.0 Mg	h	33.3			Kaltsas et al. (2007) adapted
Tank 3.0 Mg	h	47.6			Kaltsas et al. (2007) adapted
Komfler	h	16.4			Genitsariotis et al. (1996, 2000) adapted
Aero-scissors	h	0.035			Genitsariotis et al. (1996, 2000) adapted
Tools (knives etc.)	h	0.05			Kaltsas et al. (2007)
Labor	h	2.2			Pimentel and Pimentel (1996)
Orange fruit	Mg	1960			Ozkan et al. (2004)
Kiwi fruit	Mg	2420			Jarach (1985) adapted
Shoots	Mg	18.4			Pimentel (1980) adapted

a. Energy content + energy for production

Carbon footprint

The amount of fossil fuel used was determined by the amount of diesel (liters), which was used for the reservoir refilling in order to proceed to various farming activities (e.g. fertilizer, herbicide, insecticide, and fungicide application). The amount and type of fertilizer used in each farming system are shown in Table 1. Carbon dioxide, CH_4, and N_2O emissions were estimated for fertilizer production and fertilizer application in soil and fuels (IPCC 1997, 2006; Küstermann et al. 2008; EMEP/EEA 2009; ISO 2013; Pandey and Agrawal 2014). The emissions of the greenhouse gases for fertilizers and fuels were transformed to CO_2 equivalents (Eurostat 2020). Greenhouse gases emitted from fertilizer production and fertilizer (mainly N) application in soil and fuels expressed as CO_2 equivalent are the main contributors to global warming potential (GWP) in crop production (IPCC 2014). Global warming potential accounts for greenhouse gas capacity to absorb radiation and their residence time in the atmosphere. Total crop carbon footprint is the sum of the individual greenhouse gases emitted during the cultivating period divided by crop yield.

Statistical analyses

In order to explore the association among the measured energy balance or/and emissions of greenhouse gas variables, the corresponding Spearman's *rho* rank correlation index has been calculated and assessed. Indices of descriptive statistics (means and percentages %) have been also calculated. A series of Mann-Whitney (M-W) tests were performed in order to test the differences between orange and kiwi orchards relative to production coefficients and other 23 derived variables (e.g., total energy inputs, outputs, fruit production, efficiency, productivity, intensity, emissions of CO_2, CH_4, N_2O, and CO_2 equivalents). The P values in all M-W tests were computed using the Monte-Carlo method (Mehta and Patel 1996) utilizing 10,000 random samples in each run. This methodological approach leads to valid conclusions even in cases where the assumptions of the test are not satisfied. The statistical analysis was accomplished with SPSS ver. 15.0 software enhanced with the module Exact Tests (for Monte-Carlo implementation). The significance level in all hypothesis testing was predetermined at $a = 0.05$ ($P \leq 0.05$).

Results

Energy balance parameters

Table 3 presents mean values of production coefficients in orange and kiwi orchards. The nutrients' quantity in the fertilizers used was calculated to understand the demands of each crop, the needs for every nutrient, and the production coefficients of them. The production coefficients of N, Mg, Zn, fungicides, insecticides, and herbicides had statistically significant higher values in orange than in kiwi orchards. The production coefficients of P, Ca, irrigation, and machinery had statistically significant lower values in orange than in kiwi orchards. The most important production coefficients in orange and kiwi orchards were fertilizers (35.0 and 26.6%), fuels (34.2 and 25.9%), irrigation (11.7 and 25.4%), machinery (11.0 and 14%), herbicides (4.0% and 5.5%), fungicides (2.2 and 1.4%), and labor (1.4 and 0.7%).

For all orchards (n = 26), the Spearman's rank correlation coefficients were statistically significant between: human labor and machinery (*rho* = 0.44, P = 0.024), fuel and transportation (*rho* = 0.53, P = 0.005), irrigation and insecticides (*rho* = 0.83, P < 0.001), irrigation

Table 3 Mean values (min–max, standard deviation) of production coefficients in orange and kiwi orchards. Means with different exponential letters in the same row are statistically significantly different

Production coefficients	*Orange (n = 10)*	*Kiwi (n = 16)*	*P*^{1}
Fertilizers (MJ ha^{-1})	17,604.0^{a} (14,000–21,380, 2,425)	16,845.0^{a} (15,539–17,850, 661)	0.506
N (MJ ha^{-1})	14,729.0^{a} (11,130–18,550, 2,565)	12,688.8^{b} (11,501–13,356, 660)	0.049
P (MJ ha^{-1})	651.0^{b} (548–822, 93)	795.0^{a} (685–959, 78)	< 0.001
K (MJ ha^{-1})	1,635.0^{a} (1,455–1,940, 158)	1,170.0^{a} (1,407–2,134, 215)	0.485
Ca (MJ ha^{-1})	62.0^{b} (0–88, 31)	1,230.0^{a} (1,056–1,496, 125)	< 0.001
Mg (MJ ha^{-1})	259.6^{a} (176–308, 43.8)	58.9^{b} (0–176, 44.5)	< 0.001
S (MJ ha^{-1})	67.5^{a} (60–90, 10.6)	71.6^{a} (60–90, 10.0)	0.293
Zn (MJ ha^{-1})	201.6^{a} (168–252, 38.6)	127.6^{b} (84–168, 33.2)	< 0.001
Fungicides (MJ ha^{-1})	1,107.4^{a} (927–1,361, 148)	854.6^{b} (645–1,092, 155)	< 0.001
Insecticides (MJ ha^{-1})	157.6^{a} (91–242, 93)	0.0^{b} (0–0, 0)	< 0.001
Herbicides (MJ ha^{-1})	2,007.4^{a} (1,463–2,717, 419)	3,477.3^{b} (2,943–4,055, 271)	< 0.001
Diesel (MJ ha^{-1})	17,185.4^{a} (15,635–21,570, 2,078)	16,377.9^{a} (16,217–16,555, 2,425)	0.725
Labor (MJ ha^{-1})	521.9^{a} (292–925, 117)	442.1^{a} (262–741, 142)	0.505
Irrigation (MJ ha^{-1})	5,863.4^{b} (2,961–10,614, 2,258)	16,085.0^{a} (8,658–25,725, 5,449)	< 0.001
Machinery (MJ ha^{-1})	5,539.6^{b} (2,001–9,695, 93)	8,833.9^{a} (3,662–15,899, 4,265)	< 0.001
Transportation (MJ ha^{-1})	281.6^{a} (107–608, 148)	360.0^{a} (108–881, 216)	0.313

1. *P* value from Mann-Whitney test

and fungicides (*rho* = 0.55, $P = 0.004$), irrigation and herbicides (*rho* = 0.70, $P < 0.001$), fruit production and insecticides (*rho* = 0.65, $P < 0.001$), fruit production and fungicides (*rho* = 0.65, $P < 0.001$), fruit production and herbicides (*rho* = 0.51, $P = 0.008$), and fruit production and renewable inputs (*rho* = − 0.50, $P = 0.009$).

Comparisons of the orange and kiwi orchards, relative to their mean values of 23 derived variables, are presented in **Table 4**. Orange orchards showed the highest renewable inputs, fruit production, total energy outputs, energy efficiency, and productivity (Table 4). Total energy inputs, intensity, and non-renewable energy consumption were the highest in kiwi orchards (Table 4).

Table 4 Comparison between orange and kiwi orchards relative to themean values (min–max, standard deviation) of 23 derived variables. Means with different exponential letters in the same row are statistically significant different

Variables	*Orange (n = 10)*	*Kiwi (n = 16)*	*P*[1]
Renewable energy inputs (MJ ha^{-1})	14,729.0^{a} (11,130–18,550, 2,565)	4,927.7^{b} (3,536–10,920, 5,557)	< 0.001
Non-renewable energy inputs (MJ ha^{-1})	38,061.9^{a} (33,278–44,897, 4,053)	37,554.6^{a} (35,804–38,729, 831)	0.780
Total energy inputs (MJ ha^{-1})	32,210.3^{b} (25,460–40,259, 5,179)	42,482.3^{a} (35,192–52,260, 5,451)	< 0.001
Fruit production (kg ha^{-1})	53,648.0^{a} (22,455–97,987, 910)	22,376.0^{b} (10,909–39,669, 7,341)	< 0.001
Total energy outputs (MJ ha^{-1})	105,120.0^{a} (44,000–192,000, 858)	54,150.0^{b} (26,400–96,000, 17,766)	< 0.001
Energy efficiency[2]	3.3^{a} (2–5.2, 1)	1.3^{b} (0.4–2, 0.5)	< 0.001
Fertilizers energy efficiency[3]	6.1^{a} (1–12, 3)	3.2^{b} (2–5, 1)	< 0.001
Fungicides energy efficiency[3]	97.5^{a} (18–175, 42)	65.3^{b} (24–102, 23)	< 0.013
Insecticides energy efficiency[3]	716.2^{a} (138–1,219, 349)	0.0^{b} (0–0, 0)	< 0.001
Herbicides energy efficiency[3]	53.1^{a} (13–81, 21)	15.7^{b} (8–27, 5)	< 0.001
Labor energy efficiency[3]	250.6^{a} (27–658, 170)	138.2^{b} (46–274, 67)	0.023
Machinery energy efficiency[3]	24.5^{a} (3–54, 16)	8.1^{b} (2–18, 5)	< 0.001
Irrigation energy efficiency[3]	20.9^{a} (2–42, 11)	3.6^{b} (2–6, 1)	< 0.001
Fuel energy efficiency[3]	6.2^{a} (2–12, 3)	3.3^{b} (2–6, 1)	< 0.001
Transportation efficiency[3]	430.1^{a} (178–1,044, 255)	212.0^{b} (30–447, 135)	0.007
Energy productivity[4] (kg MJ^{-1})	0.7^{a} (0.1–1.5, 0.5)	0.5^{b} (0.1–0.8, 0.4)	< 0.001
Intensity[5] (MJ kg^{-1})	1.4^{b} (0.5–2.1, 1.2)	2.0^{a} (0.8–3.8, 1.6)	< 0.001
Renewable energy consumption[6] (MJ kg^{-1})	0.3^{a} (0–0.4, 0.2)	0.2^{a} (0–0.5, 0.4)	< 0.881
Non-renewable energy consumption[6] (MJ kg^{-1})	0.7^{b} (0.1–1, 0.5)	1.7^{a} (0.5–2.2, 1.1)	< 0.001
CO_2 (Mg ha^{-1})	1.41^{a} (1–1.6, 0.2)	1.49^{a} (1.2–1.9, 0.01)	0.725
CH_4 (kg ha^{-1})	0.21^{a} (0.16–0.27, 0.0)	0.24^{a} (0.17–0.22, 0.02)	0.755
N_2O (kg ha^{-1})	0.20^{a} (0.1–0.25, 0.0)	0.26^{a} (0.09–0.35, 0.13)	0.727
CO_2 equivalents per fruit production (kg kg^{-1})	0.13^{b} (0.1–0.2, 0.0)	0.25^{a} (0.16–0.37, 0.0)	< 0.001

1. M-W(*P*)=*P* value from Mann-Whitney test
2. Energy outputs per total energy inputs
3. Energy outputs per energy inputs for each factor
4. The ratio of fruit produced to the energy inputs in production
5. The reciprocal of the energy productivity index
6. Renewable or non-renewable energy inputs/fruit production

Emissions of greenhouse gases

Emissions of greenhouse gases in orange and kiwi orchards were evaluated for each cultivation practice, fertilizers, soils, and fuels. Emission indices (CO_2, CH_4, N_2O) and CO_2 equivalents/fruit production are shown in Table 4. The CO_2 equivalents/fruit production had statistically significant higher values in kiwi than in orange orchards (Table 4).

For all orchards ($n = 26$), the Spearman's rank correlation coefficients were statistically significant between: CO_2 and N (*rho* = 0.61, $P = 0.001$), CO_2 and fertilizers (*rho* = 0.68, $P < 0.001$), CO_2 and non-renewable energy inputs (*rho* = 0.74, $P < 0.001$), CO_2 and transportation (*rho* = 0.53, $P = 0.005$), CH_4 and N (*rho* = 0.62, $P = 0.001$), CH_4 and fertilizers (*rho* = 0.69, $P < 0.001$), CH_4 and non-renewable energy inputs (*rho* = 0.73, $P < 0.001$), CH_4 and transportation (*rho* = 0.55, $P = 0.005$), N_2O and N (*rho* = 0.61, $P = 0.001$), N_2O and fertilizers (*rho* = 0.69, $P < 0.001$), N_2O and non-renewable energy inputs (*rho* = 0.74, $P < 0.001$), N_2O and transportation (*rho* = 0.52, $P < 0.005$), CO_2 equivalents/fruit production and N (*rho* = 0.71, $P < 0.001$), CO_2 equivalents/fruit production and fertilizers (*rho* = 0.78, $P < 0.001$), CO_2 equivalents/fruit production and non-renewable energy inputs (*rho* = 0.84, $P < 0.001$), CO_2 equivalents/fruit production and transportation (*rho* = 0.62, $P = 0.001$).

Discussion

Energy balance parameters

For both fruit crops, the ordering pattern for the coefficients of production was fertilizers, fuels, irrigation, machinery, products for plant protection, and human labor. Fertilizer use was the highest of the inputs for both of them. Any reduction of the amounts of applied fertilizers could diminish the total energy inputs. Lower irrigation could be achieved by reducing the amount of water used and using alternative irrigation methods. The machinery modification in order to do more than one cultivation practices simultaneously (e.g., fertilizer application on the lines and weed control between the lines) could control machinery and fuel inputs. The increase of human labor could also help. The latter could contribute in the reduction of unemployment. For both studied crops, the first three most important coefficients were fertilizers, fuels, and irrigation. Michos et al. (2017) reported that irrigation and fuels were the major inputs for kiwi cultivation. The means of the most important energy inputs in descending order for other crops were electric energy (43%), fuels (41.5%), fertilization (32%), and machinery (23%) (Baldini et al. 1982; Ozkan et al. 2004; Strapatsa et al. 2006; Kaltsas et al. 2007; Litskas et al. 2011, 2013; Kehagias et al. 2015; Michos et al. 2017, 2018).

Fruit production (output) was higher in orange orchards compared to kiwi orchards. Site-specific factors (local farming practices) affected the performance of different pear production agronomic systems (Liu et al. 2010). Local farming practices, being less intensive, could have a major contribution to maintain an equilibrium between climate change and the production of farming systems. This could ensure the sustainable management of the agricultural ecosystems and lead to better profits for the farmers. Furthermore, in order to understand the role of the abovementioned agro-environmental indices on fruit production, more factors may be included as variables, such as farmers' specific characteristics (e.g., farmers' age, level of training, experience) (Raheli et al. 2017). Renewable energy inputs and total energy outputs followed the same pattern as energy efficiency, in orange orchards. By an energy standpoint, the orange orchards are more efficient than the kiwi ones and the orange farmers are more experienced and apply better management practices.

Emissions of greenhouse gases

Fertilizers (mainly N), fuels, and soil cultivation are mainly responsible for global warming potential related to crop production (IPCC 2014). The largest contributors for emissions of greenhouse gases were fertilizers, fuels and machinery in orange orchards (Nabavi-Pelesaraei et al. 2014a, b), mechanization and fertilizers in apple orchards (Milà i Canals et al. 2006), fertilizers in pear orchards (Liu et al. 2010), and fuels in vineyards (Villanueva-Rey et al. 2014). In this study, the largest contributors were fertilizers (mainly N) and fuels. Carbon footprint values were lower in orange orchards than in kiwi orchards due to better management of farming practices. The negative value of Spearman's rank correlation coefficient between renewable inputs and fruit production ($rho = -0.50$, $P < 0.01$) indicates that low renewable inputs combined with high non-renewable inputs are related with high fruit production and carbon footprint. Renewable and non-renewable inputs in wheat farms were related to carbon footprint (Khoshnevisan et al. 2013). Farmers by applying best management practices and using renewable inputs in their farms could diminish carbon footprint. Farming systems with efficient management practices, less fuel consumption, and effective use of renewable energy resources could be green systems with a low carbon footprint.

Conclusions

Kiwi orchards were more demanding in energy use than orange orchards since they had higher total inputs. Orange orchard outputs were almost double of those in kiwi orchards. This combined with the lower energy inputs indicates a cultivation more effective and friendly to the environment. The renewable inputs used in orange orchards were higher than in kiwi orchards. The lower fruit production along with the used amounts of non-renewable energy inputs for kiwi orchards resulted in slightly more greenhouse gas emissions compared to orange orchards. The climatic conditions and the soil of the studied region are suitable for the cultivation of kiwi vines. This combined with the rising price of kiwifruit led many farmers to "abandon" the orange orchards and turn to kiwi cultivation. The results of the present research showed that in short term, kiwi vines can be a more profitable cultivation than orange orchards, but in long term, the latter by having lower energy inputs and carbon footprint are more friendly to the environment. The orange orchards could create a more sustainable agricultural ecosystem than kiwi orchards. So, agricultural policy decision makers and farmers thinking the replacement of a crop with one which is "more profitable" should take under consideration the parameters related to the environment cost, as well. Sometimes, a "more profitable" crop becomes more expensive than the replaced, through high energy inputs and carbon footprint.

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