Applied Energy 149 (2015) 117–124

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Comparing organic and conventional olive groves relative to energy use and greenhouse gas emissions associated with the cultivation of two varieties

Efstratios T. Taxidis [a], George C. Menexes [b], Andreas P. Mamolos [a,*], Constantinos A. Tsatsarelis [c], Christos D. Anagnostopoulos [a], Kyriaki L. Kalburtji [a]

[a] School of Agriculture, Laboratory of Ecology and Environmental Protection, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece
[b] School of Agriculture, Laboratory of Agronomy, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece
[c] School of Agriculture, Laboratory of Agricultural Engineering, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

HIGHLIGHTS

- Multivariate statistical methods were applied to evaluate 88 olive groves.
- Three main groups (high, medium, low energy inputs) were revealed.
- The grouping was based on management practices and geographical location.
- Best farming practices regulate the balance between environment and agriculture.

ARTICLE INFO

Article history:
Received 15 January 2015
Received in revised form 24 March 2015
Accepted 25 March 2015

Keywords:
Agro-environmental indicators
Energy analysis
Greenhouse gases
Hierarchical cluster analysis
Organic farming

ABSTRACT

Organic farming is applied in olive groves in Lesvos Island the last 20 years. "Kolovi" and "Adramitiani", two dominant varieties are cultivated. Since there is limited research for energy inputs in olive groves, 62 conventional and 26 organic farms were selected during 2011–2013 in order to (a) determine the differences in energy flow among farming systems and varieties, (b) group olive groves based on energy flow indicators, (c) compare the CO_2-equivalent emissions among farming systems and varieties. A combination of univariate and multivariate statistical methods was applied. Hierarchical Cluster Analysis (HCA) revealed three farm groups, all consisted of conventional and/or organic olive groves and included both varieties. Group 1 had the lowest energy inputs, while Group 3 the highest. Fuels and transportation, as energy inputs, had the highest contribution in farms' grouping. A large number of external variables was studied, most of which (fruit production, olive oil production, pomace production, shoot production, olive oil energy production, pomace energy production, shoot energy production, total energy inputs, total energy outputs, intensity, energy efficiency, and energy productivity) had statistically significant differences among the three Groups. Management practices along with geographical location could be a reasonable explanation for the differences between the groups of studied olive groves. Group 3 had the highest non-renewable energy inputs (14,683.5 MJ ha^{-1}) and consumption (2.4 MJ kg^{-1}) and gas emissions (1.27 Mg ha^{-1} CO_2, 0.17 kg ha^{-1} CH_4, and 10.31 g ha^{-1} N_2O). Group 2 had the highest renewable energy inputs (7065.8 MJ ha^{-1}) and consumption (0.9 MJ kg^{-1}), and low CO_2-equivalent per fruit production (0.12 kg kg^{-1}). The above mentioned results show that best management farming practices introduce the use of renewable energy inputs and lead to lower gas emissions.

1. Introduction

Less intensive farming methods reduce the risk of detrimental environmental effects [1–3]. Organic farming, having low inputs, may contribute in maintaining biodiversity [4] and diminishing energy inputs through the production of energy-smart food [5–7]. Thus, organic farming conduces to climate protection, to environmental problems reduction, such as greenhouse gas emissions, and to natural resources degradation restriction [8–11]. Environmental and energy analysis of a production system could be combined to lead to the best management practices needed to be applied [6,12–15].

* Corresponding author. Tel.: +30 2310 998642; fax: +30 2310 998652.
E-mail address: mamolos@agro.auth.gr (A.P. Mamolos).

http://dx.doi.org/10.1016/j.apenergy.2015.03.128
0306-2619/

Agricultural development is related to energy resources. When compared to other energy consuming sectors, agriculture does not consume a lot of energy [16]. Less intensive farming systems use better farming practices and diminish gas emissions. The sustainability in production systems requires knowledge of energy use in agriculture. The various sources and uses of energy inputs at farms have been studied [17,18], but the research worldwide on the different farm production systems is limited.

In the Mediterranean basin, *Olea europaea* subsp. *Europaea* is a native evergreen tree or shrub. It is a key crop in Mediterranean countries. Olive trees are well adapted to arid zones with a low fruit production due to scarcity of water, especially in dryland areas with Mediterranean climate [12,19,20]. Applying a less intensive management will reduce inputs without significant repercussions on the productivity of the land and improve their energy efficiency. The CAP (Common Agricultural Policy) plays a key role to production process. It mitigates the impact of cycles of drought in the Mediterranean basin. Researchers and society are recently showing a grown interest for the environmental problems and their repercussions on food safety. Low input farming systems, such as organic, can probably contribute in reducing production costs, using human labor efficiently, and protecting the environment [6,9]. Although researchers considered energy analysis of olive production as a tool to determine the highest energy consuming operations [11,12,20], there is limited research in the comparison of organic and conventional olive groves in energy flow (renewable and not renewable) along with gas emissions. Both are very important issues for sustaining the equilibrium of the environment.

According to FAO [21], olive groves cover approximately 10.2 million ha worldwide and 934,400 ha with a fruit production of 2,080,815.4 Mg in Greece. In Lesvos Island, olive tree is one of the dominant species. According to the local Department of Agricultural Development, organic farming as an alternative management is applied in several olive groves of Lesvos. Traditional and unique varieties (“Adramitiani” and “Kolovi”) are cultivated in the island [22]. A combination of the island varieties under different management systems in relation to the olive groves geographical location thought to be an interesting subject to be studied.

This research was conducted, by selecting conventional and organic olive groves to (a) determine the differences in energy flow (renewable and non-renewable) among the two farming systems and the two varieties, (b) group olive groves based on energy flow indicators, (c) compare the CO_2-equivalent emissions among farming systems and varieties.

2. Materials and methods

Olive trees cultivated mainly in the east part of Lesvos Island under dry conditions cover about 40,215.8 ha. According to the local Department of Agricultural Development (Olive Cultivation Register), the 2.5% of the cultivated areas in the island is covered by about 410 organic olive groves and the rest is covered by more than 10,000 conventional ones. Organic farmers are applying the regulations EC 834/2007, EC 889/2008, and EC 271/2010. During the years 2011–2013, 26 organic olive groves out of 264 (10%) and 62 conventional out of 620 (10%) were selected with proportional stratified random sampling (Appendix A). All olive groves had from moderate to steep slopes and were easily approached. Their age according to Olive Cultivation Register was more than 100 years with a tree density ranged from 93 to 250 individuals ha^{-1}. The altitude of the olive groves ranged from 50 to 400 m, and their size ranged from 0.4 to 10 ha. The olive growers were occupied with olive tree cultivation for more than 30 years. The dominant varieties are “Kolovi” (*O. Europaea* var. pyriformis) covering the 70% of the olive groves and “Adramitiani” (*O. europaea* var. med. subrotunda) covering the 20% [22]. “Kolovi” is cultivated in 44 conventional and 16 organic of the selected olive groves. Its fruits contain 25% olive oil. “Kolovi” produces high quality olive oil and table olives as well [22]. “Adramitiani” is cultivated in the rest of the selected olive groves. Its fruits contain 22% olive oil which has excellent quality [22]. In the studied olive groves, according to the Greek National Meteorological Service, the mean annual temperature, precipitation, and relative humidity were 22 ± 5 °C, 624 ± 42 mm, and 67 ± 22% (mean ± 1 Standard Error; $n = 15$ years), respectively.

In order to calculate energy indices a methodological scheme, adapted to agriculture Life Cycle Assessment (LCA), was applied [23–28]. This scheme involved four stages. In stage 1, the goals were (a) to calculate the energy used and the greenhouse gas emissions from fuels, fertilizers, and soil, in conventional and organic olive groves, and (b) to compare them in order to determine the farming system with the best energy efficiency and the least gas emissions. The functional unit was the olive fruit yield per hectare. The system boundaries started at the production and the application of fertilizers and pesticides, the machinery production, the soil preparation, etc., and ended at the removal of the olive fruit production. In stage 2, the energy inputs and outputs of the farming systems and the greenhouse gas emissions for fuels, fertilizers, and soil were calculated. In stage 3, the effects of the farming systems on olive fruit yields and greenhouse gas emissions were examined. In stage 4, the results were evaluated and discussed.

Appendix B presents the farm management practices of the two farming systems during the years 2011–2013. The estimation of the energy encapsulated in the olive groves was based on the farmers' schedule, the duration of each operation, the number of machines and laborers, the field operation inputs (e.g. pesticide application), and the production coefficients (e.g. fuels and fertilizers). This energy was enumerated by recording material used, fuel consumption, and the duration of each operation. The machinery's embodied energy was determined using the conversion factors in Appendix C. Organic farming depends mainly on human labor, which was estimated by using the convention factors in Appendix C.

Fuels and inorganic fertilizers especially nitrogen, and soil, are the largest contributors to global warming potential in crop production [16]. The fuel (litters) consumed by the machinery for field operations (e.g. application of fertilizers, weed control) was used to determine fossil energy. Carbon dioxide, CH_4, and N_2O, and CO_2-equivalents emissions were estimated for all cultivation practices [29–34], for fuel [29,30], for soil [35], and fertilizers [30,36]. The greenhouse gas emissions equivalents for fertilizers (based on their composition), soil, and fuels are shown in Appendix D.

2.1. Statistical analysis

Variability of the seven production coefficients' variables (fertilizers, fuel, plant protection products, labor, machinery, transportation, and harvesting nets) within each “farming system × variety” combination (two farming systems, conventional and organic, and two varieties, “Kolovi” and “Adramitiani”) was measured by the corresponding univariate and multivariate coefficients of variation (CV); the multivariate CV was computed according to a new method proposed by Albert and Zhang [37]; this index is computationally attractive and takes into account not only the total multivariate variation of the seven variables but also their co-variation. Multivariate CV is given by the formula: $[\mathbf{x}^T\mathbf{S}\mathbf{x}/(\mathbf{x}^T\mathbf{x})^2]^{1/2}$, where $\mathbf{x}$ is the vector of sample means ($\mathbf{x}^T$ is the transposed vector) and $\mathbf{S}$ the sample variance–covariance matrix. Associations between the production coefficients' variables within each farming system were examined using the Spearman's *rho* rank correlation coefficient. Differences between varieties, farming systems, and their combination, relative to the olive groves' altitude (m), size (ha), and density (trees ha^{-1}), were tested by a series of 2×2 ANOVAs.

In order to examine the effect of varieties and farming systems on the seven production coefficients' variables, on the total inputs, and on 19 variables (variables 4, 5, 7–23, in Appendix E) a series of 2×2 ANOVAs were performed. Prior to the analyses, the values (X) of the variables were $\log_{10}(X+1)$ transformed as an attempt to achieve normality and homoscedasticity of the residuals of the ANOVA models. Due to great variability of the data, homoscedasticity remained an issue even after transformation. In order to validate the follow up comparisons of mean values, first a series of *t*-tests, adjusted for unequal variances, was performed for post-hoc means' comparisons within main effects (between the two farming systems and between the two varieties) and, second, a series of Games–Howell multiple comparison procedures [38,39] was adopted for testing the differences among the four interaction means. The Games–Howell multiple comparisons procedure is valid for non uniform sample sizes, as long as the sample size in each treatment is greater than 5, and heterogeneous variances. It has higher power than other tests suitable for unbalanced designs with unequal variances [40,41].

The Hierarchical Cluster Analysis (HCA) method was performed on the $\log_{10}(X+1)$ transformed values of the seven production coefficients' variables in order to reveal groups of farming systems [6,9,42]. Ward's method [43] was used for cluster construction. The dissimilarity between the studied olive groves was measured with the squared Euclidian distance [44]. Ward's method (or minimum variance criterion) uses an Analysis of Variance approach in cluster constructing and merging. It minimizes the total within-cluster variance. Specifically, it minimizes the sum of squares of any two clusters that are formed at each step of the analysis. The sums of squares are easier to interpret because if they are divided by the total sum of squares the result is the proportion of variance accounted by the clustering. The whole process it can be considered as a decomposition of the total multivariate variance according to the mathematical expression: $\mathbf{T} = \mathbf{B} + \mathbf{W}$, where $\mathbf{B}$ is the between clusters variance and $\mathbf{W}$ is the summed within clusters variance. The initial distances between individual clustering objects (olive groves in our case) must be squared Euclidean distances (or proportional to), in order, the above described approach, to make sense in the frame of an optimization process. The upper tailed rule was used for checking the cluster's solution statistical significance [45]. The contribution of each of the seven production coefficients' variables in cluster construction was evaluated using the magnitude and the statistical significance of the corresponding coefficients of determination R^2; these coefficients were computed from multiple runs of one-way ANOVAs, where cluster's membership was considered as the independent variable and the production coefficients as the dependents. The value of R^2 indicates the percentage of variance of a dependent variable explained by the differences between clusters. The index R^2 is mathematically equivalent to the index "eta squared", which is a measure of cluster's membership effect size [46]. This index is estimated using the formulae: $\eta^2 = R^2 = \frac{SS_{Between\ groups}}{SS_{Total}}$, where *SS* stands for "sum of squares". Differences between cluster means, relative to the seven production coefficients' variables and the total inputs (MJ ha^{-1}), were tested by the Games–Howell procedure too. Before running HCA and one-way ANOVAs, production coefficients' values were $\log_{10}(X+1)$ transformed for (a) smoothing and homogenizing the variance of heavily skewed variables' distributions [47] and overcoming the problem of some variables having zero values and (b) validating the statistical significance of the R^2 (or η^2) coefficients. HCA was used to reveal unobserved grouping structures among the olive groves without assuming any a priori hypotheses relative to the mechanism ("farming system $\times$ variety" combinations) that generated the data of this study [48,49]. In order (a) to visualize the olive groves' variability within and between the four "farming system $\times$ variety" combinations (1st approach of labelling the olive groves) and the variability within and between the groups of farms resulted from HCA (2nd approach) and (b) to evaluate from a descriptive point of view, not model based, the discrimination ability of the two labelling approaches of the farms, 90% normal contour ellipsoids were plotted [50,51]. The construction of these three-dimensional ellipses, that encompass a specified portion of points, was based on the first three principal components' scores resulted from the application of Principal Component Analysis [44] on the $\log_{10}(X+1)$ transformed values of the seven production coefficients' variables.

A number of Mann–Whitney (M–W) tests were applied for examining the pair-wise differences between clusters concerning the values of 23 "external" variables (Appendix E), which were not entered in the cluster analysis. The purpose of these analyses was to enrich clusters' profile and evaluate the external validity of cluster solution [52]. M–W tests were performed only in cases where an omnibus Kruskal–Wallis (K–W) test showed significant differences. The observed significance level (*P*-value) in all K–W and M–W tests was calculated by the Monte-Carlo simulation method [53], using 10,000 bootstrap samples in each run. This method leads to safe inferential conclusions even in cases where the methodological assumptions and presuppositions of the non-parametric tests are not fulfilled (e.g. large samples, symmetrical distributions, absence of outliers, independent observations, and random samples). HCA was accomplished with SPSS ver. 15.0 (accompanied with the module Exact Tests used for Monte-Carlo simulation) and Clustan ver. 5.27 (the latter used for performing the upper tailed rule test). Normal contour ellipsoids were plotted using the JMP ver.9.0 software. The input order stability of the cluster solution was tested and validated through a bootstrap procedure [54] supported by PermuCLUSTER ver.1.0 software (an SPSS addin); this software was also used for the computation of the cophenetic correlation, a useful index for cluster solution validation. The significance level in all statistical tests was preset at $P < 0.05$.

3. Results

3.1. Energy use

The differences among means of farming systems and varieties for the altitude, olive grove size, and tree density were not statistically significant. Over all studied olive groves ($n = 88$) the minimum, median, and maximum values of the altitude, size and tree number were 50.0, 200.0, 400.0 m, 0.2, 1.0, 13.0 ha, and 25, 154, 200 trees ha^{-1}, respectively.

In conventional olive groves ($n = 62$), the Spearman's rank correlation coefficient was significant between (a) labor and machinery ($r_s = 0.53$, $P < 0.001$), plant protection products ($r_s = 0.48$ $P < 0.001$), and harvesting nets ($r_s = 0.48$, $P < 0.001$), (b) fuel and machinery ($r_s = 0.78$, $P < 0.001$), plant protection products ($r_s = -0.29$, $P = 0.023$), and harvesting nets ($r_s = -0.29$, $P = 0.023$), and (c) tree density and plant protection products ($r_s = 0.53$, $P < 0.001$), harvesting nets ($r_s = 0.53$, $P < 0.001$), olive groves size ($r_s = 0.89$, $P < 0.001$), and total energy outputs ($r_s = 0.48$, $P < 0.001$). In organic olive groves ($n = 26$), significant correlations were found between (a) machinery and labor ($r_s = 0.43$, $P = 0.030$) and fuel ($r_s = 0.74$, $P < 0.001$), (b) olive groves size and plant protection products ($r_s = 0.83$, $P < 0.001$), total energy inputs ($r_s = -0.49$,

$P < 0.011$), tree density ($r_s = 0.86$, $P < 0.001$), and altitude ($r_s = -0.42$, $P = 0.034$), and (c) tree density and total energy inputs ($r_s = -0.45$, $P = 0.020$), total energy outputs ($r_s = 0.49$, $P = 0.012$), and plant protection products ($r_s = 0.99$, $P < 0.001$).

Coefficients of variation (CVs%) for each production coefficient in each farming system-variety combination were high ranging from 26.1 (labor, Organic-Kolovi) to 228.3% (fertilizers, Organic-Kolovi) (Table 1). The multivariate CVs ranged from 93.8 (Conventional-Adramitiani) to 112.3% (Conventional-Kolovi) (Table 1).

For both farming systems, "Kolovi" had higher fertilizer and labor inputs than "Adramitiani", which had higher transportation inputs in organic olive groves (Table 2). Means averaged over all varieties in each farming system were statistically significant low for plant protection products and fuel in organic olive groves, while fertilizers and transportation were high (Table 2).

The comparisons among the means of farming systems and varieties for 15 energy indices are shown in Appendix F. The means of the farming systems averaged over all varieties for the energy efficiency and the renewable energy inputs were significantly higher, while for the non-renewable energy inputs, and non-renewable energy consumption were significantly lower in organic than in conventional olive groves (Appendix F). The means of the varieties averaged over all farming systems for fruit, olive oil, pomace and shoot production, and olive oil, pomace and shoot energy production, and total energy outputs, energy efficiency, and renewable energy inputs were significantly higher, while non-renewable energy inputs and non-renewable energy consumption were significantly lower for "Kolovi" than "Adramitiani" (Appendix F). The means of varieties in each farming system for fruit, olive oil, pomace and shoot production, and olive oil, pomace and shoot energy production, and total energy outputs, renewable energy inputs, and energy efficiency were statistically significant lower for "Adramitiani" in conventional than in organic olive groves, while the non-renewable energy inputs and consumption were lower for "Kolovi" in organic than in conventional olive groves (Appendix F).

HCA resulted to three main groups of the studied olive groves (Fig. 1). Group 1 included olive groves with the lowest energy inputs (19 conventional and 7 organic with "Kolovi" and 6 conventional and 5 organic with "Adramitiani"), followed by Group 2 with intermediate inputs (4 conventional and 4 organic with "Kolovi" and 2 organic with "Adramitiani"), and Group 3 with the highest (21 conventional and 5 organic with "Kolovi" and 12 conventional and 3 organic with "Adramitiani"). The upper tailed criterion showed that the three clusters' solution was significant ($t(86) = 3.78$, $P < 0.001$). The cophenetic correlation coefficient having high value ($r_c = 0.84$, $P < 0.001$) verifies that the dendrogram showed in Fig. 1 preserves the pair-wise distances between the original variables. Means of all groups relative to production coefficients' variables are presented in Table 3. The highest contributors in cluster formation were, in descending order, fertilizers, fuel, labor, harvesting nets, and machinery. This is clear from their R^2 values (Table 3). High deviations among the three Groups were found for fertilizers, plant protection products, fuel, and machinery (Fig. 2). Mean values for production coefficients of fuel and machinery of Group 1 were significantly low, intermediate for Group 2, and high for Group 3 (Table 3). Also, mean values for labor and harvesting nets of Group 3 were significantly low (Table 3). Finally, the mean values for fertilizers of Groups 2 were the highest.

The variability within and between the three farm groups concerning the seven production coefficients' variables, and the corresponding variability within and between the four combinations "farming system × variety" are shown in Fig. 3. The three-dimensional 90% ellipses provided support that there was a clearer separation of the three farm groups resulted from HCA (Fig. 3b) than the separation resulted from their a priori grouping according to the four combinations "farming system × variety" (Fig. 3a).

The comparison of the three clusters of olive groves showed that in Group 2, tree density, renewable energy inputs and consumption were significantly higher compared to the other groups (Table 4). In Group 3, the production of fruit, olive oil, pomace and shoot, the energy production of olive oil, pomace and shoot, and the total energy outputs were significantly lower, while the non-renewable energy inputs and consumption were significantly higher, when compared to the other groups (Table 4). Total energy inputs and intensity were significantly low in Group 1 and high in Group 3, while the opposite was observed for energy efficiency and energy productivity (Table 4).

Table 1
Coefficients of variation (CVs%) of each production coefficient within the combinations of farming systems and varieties.

Farming system-variety	Labor	Fuel	Machinery	Fertilizers	Plant protection products	Transportation	Harvesting nets	Multivariate CV
Conventional-Kolovi	51.6	168.3	66.1	421.3	38.0	99.1	38.0	112.3
Conventional-Adramitiani	73.5	110.9	83.9	[a]	34.0	103.9	34.0	93.8
Organic-Kolovi	26.1	150.5	57.1	228.3	73.9	84.2	44.8	102.5
Organic-Adramitiani	73.1	114.6	41.7	212.1	67.7	118.7	32.2	108.7

[a] Not applicable.

Table 2
Comparisons of production coefficients' means (untransformed values) for: (a) the combinations 'farming system × variety' (b) the farming systems over all varieties, and (c) the varieties over all farming systems. Means in the same row followed by different exponential letters are statistically significant different ($P < 0.05$) according to Games–Howell test [for (a) comparisons] and t-test [for (b and c) comparisons].

Production coefficients	Conventional (a)		Organic (a)		Farming systems (b)		Varieties (c)	
	Kolovi ($n = 44$)	Adramitiani ($n = 18$)	Kolovi ($n = 16$)	Adramitiani ($n = 10$)	Conventional ($n = 62$)	Organic ($n = 26$)	Kolovi ($n = 60$)	Adramitiani ($n = 28$)
Fertilizers (MJ ha^{-1})	293.8^{b}	0.0^{a}	2848.4^{c}	597.3^{b}	208.5^{a}	1982.6^{b}	957.0^{b}	213.3^{a}
Plant protection products (MJ ha^{-1})	2083.4^{b}	1540.4^{b}	0.8^{a}	0.9^{a}	1925.8^{b}	0.9^{a}	1528.1^{a}	990.6^{a}
Labor (MJ ha^{-1})	1050.1^{b}	621.0^{a}	984.2^{b}	739.8^{ab}	925.5^{a}	890.2^{a}	1032.5^{b}	663.4^{a}
Fuel (MJ ha^{-1})	4727.5^{a}	8628.4^{a}	3194.0^{a}	1611.5^{a}	5860.0^{b}	2585.4^{a}	4318.5^{a}	6122.4^{a}
Machinery (MJ ha^{-1})	678.5^{a}	590.2^{a}	571.6^{a}	316.6^{a}	652.9^{a}	473.5^{a}	650.0^{a}	492.5^{a}
Transportation (MJ ha^{-1})	2086.4^{a}	2792.9^{a}	2011.4^{a}	8335.1^{b}	2291.5^{a}	4443.6^{b}	2066.4^{a}	4772.2^{b}
Harvesting nets (MJ ha^{-1})	245.6^{a}	181.6^{a}	262.0^{a}	257.4^{a}	227.0^{a}	260.2^{a}	250.0^{a}	208.7^{a}
Total inputs (MJ ha^{-1})	11165.2^{a}	14,354.4^{a}	9872.3^{a}	11,858.6^{a}	12,091.1^{a}	10,636.3^{a}	10,820.5^{a}	13,463.0^{a}

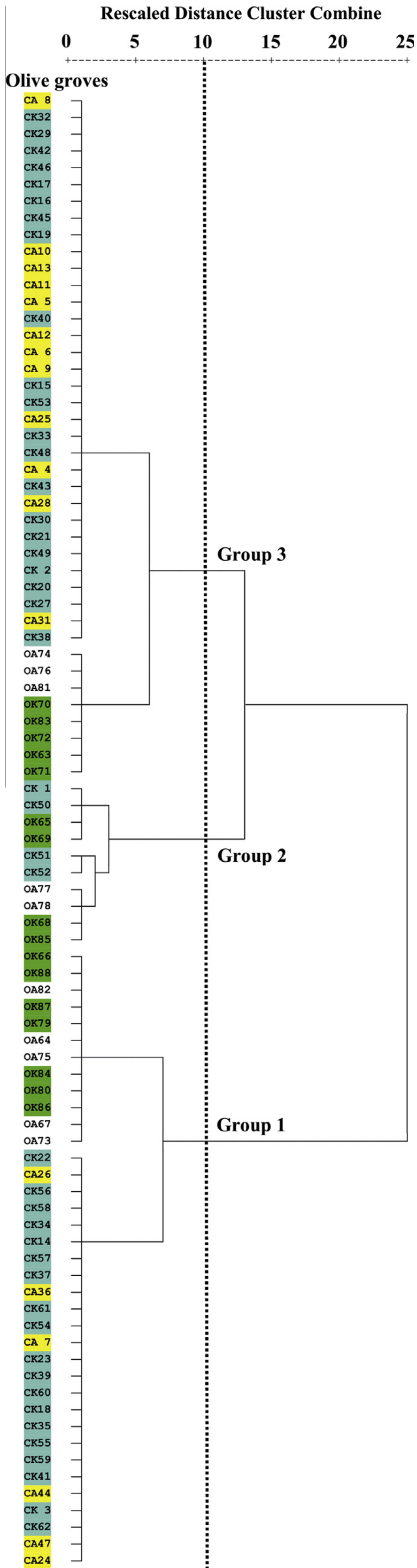

Fig. 1. Dendrogram of Hierarchical Cluster Analysis (HCA) with respective groups of selected conventional and organic olive groves cultivated with Kolovi (CK with blue shade and OK with green shade, respectively) and Adramitiani (CA with yellow shade and OA with white, respectively). Vertical dashed line provides a visual aid for cluster separation. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 3
Group means (untransformed data) relative to production coefficients and the respective R^2 coefficients derived from transformed data. Means in the same row followed by different exponential letters are statistically significant different ($P < 0.05$) according to Games–Howell test.

Production coefficients	Group 1 ($n = 37$)	Group 2 ($n = 10$)	Group 3 ($n = 41$)	R^2	P
Fertilizers (MJ ha^{-1})	0.00^a	6447.30^b	0.00^a	0.982	<0.001
Plant protection products (MJ ha^{-1})	1505.00^a	999.50^a	1310.80^a	0.057	0.083
Labor (MJ ha^{-1})	1003.10^b	1035.70^b	806.26^a	0.290	0.018
Fuel (MJ ha^{-1})	0.00^a	2057.50^b	9999.10^c	0.897	<0.001
Machinery (MJ ha^{-1})	401.60^a	587.70^b	781.70^c	0.206	<0.001
Transportation (MJ ha^{-1})	2617.70^a	2243.20^a	3373.70^a	0.002	0.903
Harvesting nets (MJ ha^{-1})	260.30^b	287.70^b	203.20^a	0.289	0.007

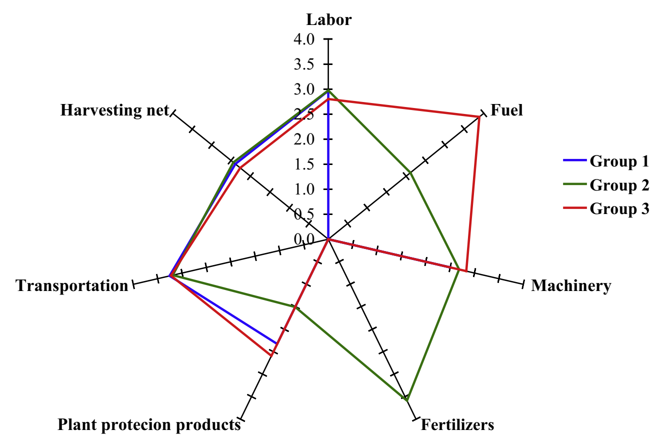

Fig. 2. Profiles of the three olive groves groups according to the mean values of the seven production coefficients [original values (X) were log($X + 1$) transformed].

3.2. Greenhouse gas emissions

Greenhouse gas emissions of olive groves located in Lesvos Island and cultivated under the two farming systems were estimated for fertilizers, soil, and fuels. In both farming systems, the Spearman's rank correlation coefficient was significant (a) between CO_2-equivalent emissions per fruit production and total energy inputs ($r_s = 0.64$, $P < 0.001$ for conventional olive groves ($n = 62$); $r_s = 0.53$, $P = 0.006$, for organic olive groves ($n = 26$)) and (b) between CO_2-equivalent emissions per fruit production and total energy outputs ($r_s = -0.43$, $P = 0.001$; $r_s = -0.57$, $P = 0.003$) for conventional and organic olive groves, respectively.

The comparisons among the means of farming systems and varieties for greenhouse gas emissions are shown in Appendix G. They were not affected either by farming or by the varieties with the only exception of N_2O-emissions, which were significantly lower for "Kolovi" in organic than in conventional olive groves (Appendix G). Comparing the three clusters of olive groves, CO_2-equivalent per fruit production was significantly higher in Group 3 than the other groups (Table 4).

4. Discussion

4.1. Energy use

The ordering pattern of the most important production coefficients differed in the studied farming systems. In conventional olive groves, fuel, transportation, plant protection products, labor, machinery, harvesting nets, and fertilizers were 48.5%, 19.0%,

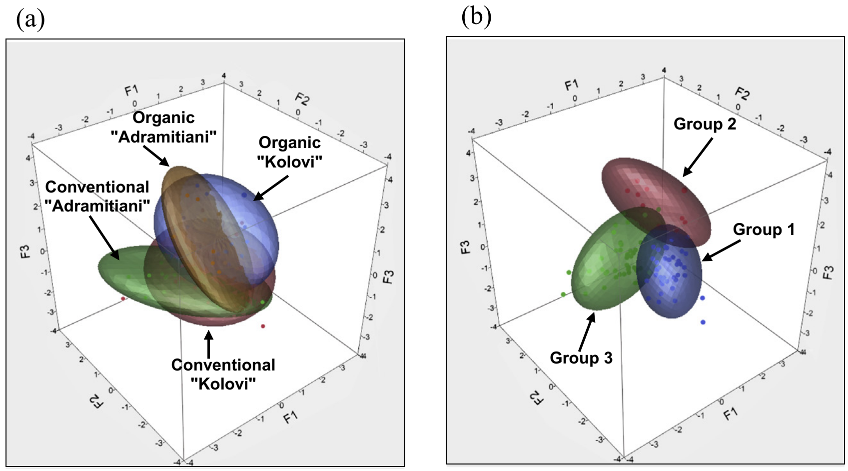

Fig. 3. (a) System × variety separation with 90% normal contour ellipsoids on the first three principal components (62.6% of total variance) of the seven inputs variables, (b) cluster separation with 90% normal contour ellipsoids on the first three principal components (62.6% of total variance) of the seven inputs variables.

Table 4
Comparison of the olive grove groups relative to mean values on 23 external variables. Mean values in the same row followed by different exponential letter are statistically significant different ($P < 0.05$) according to a series of Mann–Whitney tests.

Variables	Group 1	Group 2	Group 3	K–W (*P*)[a]
Altitude (m)	216.8^{a}	250.0^{a}	189.5^{a}	0.137
Olive grove size (ha)	1.7^{a}	1.7^{a}	1.8^{a}	0.74
Density (trees ha^{-1})	189^{b}	195^{a}	107^{b}	0.049
Renewable energy inputs (MJ ha^{-1})	1665.1^{a}	7065.8^{b}	1791.2^{a}	<0.001
Non-renewable energy inputs (MJ ha^{-1})	4122.7^{a}	6592.7^{a}	14,683.5^{b}	<0.001
Total energy inputs (MJ ha^{-1})	5987.7^{a}	13,658.5^{b}	16,474.7^{c}	<0.001
Fruit production (kg ha^{-1})	9859.1^{b}	10,374.0^{b}	7803.3^{a}	0.039
Olive oil production (l ha^{-1})	1952.7^{b}	2054.7^{b}	1545.5^{a}	0.039
Pomace production (kg ha^{-1})	6573.2^{b}	7264.4^{b}	5131.4^{a}	<0.001
Shoot production (kg ha^{-1})	1735.3^{b}	1917.8^{b}	1363.8^{a}	0.007
Olive oil energy production (MJ ha^{-1})	73,811.1^{b}	77,666.2^{b}	58,420.6^{a}	0.039
Pomace energy production (MJ ha^{-1})	136,394.5^{b}	150,736.0^{b}	106,476.8^{a}	0.01
Shoot energy production (MJ ha^{-1})	31,930.1^{b}	35,287.5^{b}	25,094.6^{a}	0.007
Total energy outputs (MJ ha^{-1})	242,135.8^{b}	263,689.7^{b}	189,992.0^{a}	<0.001
Energy efficiency[b]	50.1^{c}	26.8^{b}	15.4^{a}	<0.001
Energy productivity[c] (kg MJ^{-1})	2.0^{c}	1.0^{b}	0.6^{a}	<0.001
Intensity[d] (MJ kg^{-1})	0.6^{a}	1.7^{b}	2.7^{c}	<0.001
Renewable energy consumption[e] (MJ kg^{-1})	0.2^{a}	0.9^{b}	0.3^{a}	<0.001
Non-renewable energy consumption[e] (MJ kg^{-1})	0.5^{a}	0.7^{a}	2.4^{b}	<0.001
CO_2 (Mg ha^{-1})	0.84^{a}	0.88^{a}	1.27^{b}	<0.001
CH_4 (kg ha^{-1})	0.11^{a}	0.12^{a}	0.17^{b}	<0.001
N_2O (g ha^{-1})	6.83^{a}	7.14^{a}	10.31^{b}	<0.001
CO_2-equivalents per fruit production (kg kg^{-1})	0.10^{a}	0.12^{a}	0.22^{b}	<0.001

[a] K–W(*P*) = *P*-value from Kruskal–Wallis test.
[b] Energy outputs/total energy inputs.
[c] The ratio of fruit produced to the energy inputs in production.
[d] The reciprocal of the energy productivity index.
[e] Renewable or non-renewable energy inputs/fruit production.

15.9%, 7.7%, 5.4%, 1.9%, and 1.7%, respectively. In organic, transportation, fuel, fertilizers, labor, machinery, harvesting nets, and plant protection products were 41.8%, 24.3%, 18.6%, 8.4%, 4.5%, 2.4%, and 0.1%, respectively. Fuel and transportation were the highest energy inputs for both farming systems, while, harvesting nets, machinery, and labor were low. Hemmati et al. [20] found that, for Iranian olive groves, chemical fertilizers had the highest contribution in energy inputs (63.2%) followed by electricity (20.8%). In other studies concerning other crops, the major energy input was either fuels or fertilization or electricity [8,9,55–57].

Statistical significant associations were found between studied variables (e.g. labor and machinery, tree density and harvesting nets) in both farming systems. This could be probably related to the specific farming practices applied in the olive groves of the island. The range of the coefficients of variation for each production coefficient in the "farming system × variety" combinations and the high values of the multivariate coefficients of variation could be attributed to farms' geographical location, production coefficients, and local farming practices, which are very important issues in taking decisions for the future of agriculture. Litskas et al. [42] ended in the same conclusions for vineyards.

In conventional olive groves, fruit, olive oil, pomace production, renewable energy inputs, and energy efficiency were low for "Adramitiani" and high for "Kolovi". In organic olive groves, non-renewable energy inputs and consumption were low for "Kolovi". These indicate that "Kolovi" is the best choice for environmental protection. Guzmán and Alonso [5] comparing energy use in conventional and organic olive oil production in Spain stated that organic growing olive trees had greater non-renewable energy efficiency that the conventional ones.

In Lesvos Island, olive groves are not irrigated. This resulted in lower total energy inputs compared to olive groves in Thassos Island [12] and in Chalkidiki [58,59]. Energy efficiency and energy productivity were higher in Lesvos Island than in Thassos Island [12] and in Chalkidiki [58,59], while intensity was lower. These three indexes are based on the encapsulated energy of non-renewable and renewable energy inputs, which were not studied separately in any previous research on energy inputs in olive groves. It should be mentioned that the sample of the studied olive groves was larger when compared to other studies. In addition, the combination of univariate and multivariate statistical methods used in this study offered an aid for the indepth examination of the variability between the studied olive groves relative to the energy inputs and outputs. The values of energy efficiency are $\geqslant 1.0$ because solar energy (radiation or heat) is not included in total energy estimation [60].

The visualization of the seven production coefficients' variability revealed that the farm Groups resulted from HCA were more distinct than the groups based on their a priori labelling according to the "farming system × variety" combinations. This was probably due to the variation of the production coefficients as affected by the traditional management practices of the farms and the geographical location [42]. Although, the 24 studied olive groves (12 conventional and 12 organic) of Thassos Island [12] were not organized in Groups of low or high energy inputs, there was an indication that there were differences related to the geographical location. On the other hand, farming systems had no effect of energy inputs and this was related to the well adapted variety to environmental conditions and the cultivation practices. Liu et al. [61] related the differences found among pear production farming systems to site-specific factors two of which were geographical location and local farming practices.

4.2. Greenhouse gas emissions

The highest non-renewable energy inputs of Group 3 led to the highest non-renewable energy consumption and gas emissions. Proietti et al. [34] studying the carbon foot print of an Italian intensive olive grove found that the annual average value for the first 11 years of CO_2-equivalent emissions was 1.507 Mg ha^{-1}, having the highest value during the first year due to the many mechanized operations and fertilization. Robain-Alves et al. [62] stated that the use of N per cultivated area (i.e. fertilizers) was an important factor to gas emissions increasement, while a decreasement was observed when labor productivity increased. Thus, the implementation of best management farming practices using renewable energy inputs which lead to lower gas emissions could be used as a protection aid for sensitive areas [8,12,61,63,64]. Management practices along with geographical location could be a reasonable explanation for the differences between the groups of studied olive groves. This was also found for vineyards in Cyprus [42]. This reveals the future focus on the importance of geographical location, which by being related to altitude, farm distance from farmers' house and post harvest processing units can influence not only the energy inputs but the greenhouse gas emissions as well. So, both geographical location and management practices could affect the services and functions and regulate the balance environment and agriculture.

5. Conclusions

The HCA formed three distinct farm groups of the studied 88 (26 organic and 62 conventional) olive groves. Group 1 included olive groves with the lowest energy inputs and Group 3 with the highest. The higher energy inputs were fuel and transportation. "Adramitiani" had the lowest values of fruit, olive oil, and pomace production, and renewable energy inputs and energy efficiency. Statistical comparisons showed that most of the external variables (fruit production, olive oil production, pomace production, shoot production, olive oil energy production, pomace energy production, shoot energy production, total energy inputs and outputs, intensity, energy efficiency and productivity) had significant differences among the three Groups. Management practices along with geographical location could be a reasonable explanation for the differences between the groups of the studied olive groves. Group 3 had the highest non-renewable energy inputs leading to high non-renewable energy consumption and CO_2, CH_4, and N_2O-emissions. Group 2 had high renewable energy inputs, renewable energy consumption, and low CO_2-equivalent per fruit production. These results could be used as a tool for sensitive areas to apply best management farming practices by introducing the use of renewable energy inputs and leading to lower gas emissions. Additionally, they support a mechanism to quantify improvements (balance between environment and agriculture) that may influence energy inputs leading to more efficient production techniques.

Acknowledgement

We thank emeritus professor A. Gatzianas (Aristotle University of Thessaloniki, Greece), for his helpful comments and corrections to earlier manuscripts. We are grateful to the local Department of Agricultural Development (Olive Cultivation Register) of the Prefecture of Lesvos and the farmers who participated in this research.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.apenergy.2015.03.128.

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