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Energy flow, carbon and water footprints in vineyards and orchards to determine environmentally favourable sites in accordance with Natura 2000 perspective

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A B S T R A C T

The assessment of energy flow in agroecosystems can help to select the best management strategies for cultivated species. Conventional and organic vineyards and kiwi orchards along with conventional, integrated and organic apple orchards were selected from sites located both in and out Natura 2000 network to (a) determine energy efficiency of the farming systems, (b) estimate gas emissions along with carbon and water footprint, (c) reveal groups of farming systems on the basis of their similarities to energy efficiency, carbon and water footprint. Forty one farms (ten conventional and five organic vineyards; five conventional and three organic kiwi orchards; six conventional, four organic and eight integrated apple orchards) were selected during the years 2010–2013 in the Prefecture of Pella, northern Greece. Hierarchical Cluster Analysis (HCA) revealed three main Groups of farms. In descending order, the contributors in cluster formation were CO_2-equivalent, energy efficiency, and water footprint. Group 3 had the highest CO_2-equivalent per fruit production. The vineyards of Group 3 located at the highest altitude resulted in highest labor, diesel, branch shoring, intensity, energy consumption and greenhouse gas emissions (CO_2, CH_4, and N_2O). They showed the lowest irrigation, total water consumption, energy outputs, and energy productivity. Group 2 had the highest water consumption per fruit production. Group 1 showed high environmental advantages since it had the lowest CO_2-equivalent, the highest energy efficiency, and intermediate water footprint. The above indices are useful to decision makers for seeking crops and farming systems in order to regulate the fragile balance between Natura 2000 network and agriculture.

1. Introduction

The habitats conservation Directive (92/43/EEC) has established the European ecological Natura 2000 network. The role of agriculture on habitats in or close to Natura 2000 network sites can be considered as a main issue (Kallimanis et al., 2008), useful to decision makers for seeking crops and farming systems in order to regulate the fragile balance between Natura 2000 sites and agriculture. Intensification of agricultural production results in high greenhouse gas emissions (Clune et al., 2017). The impacts of agriculture on climate change and the environment could be reduced by using less intensive farming practices (Müller et al., 2006; Dantsis et al., 2010).

In the EU, greenhouse gas emissions from agriculture reach 470.6 Mt of CO_2-equivalent per year, which equals about 10% of the total gas emissions (Eurostat, 2017). The goal of reducing greenhouse gas emissions up to 80–95% by 2050 (ECF, 2010; PA, 2015) requires the streamlining of methods and techniques for the agricultural ecosystems (Haas et al., 2001; Litskas et al., 2011; Adewale et al., 2016). Low intensity farming systems, such as integrated and

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organic farming, may contribute in diminishing inputs of energy, greenhouse gas emissions (Kehagias et al., 2015; Taxidis et al., 2015) and confine the degradation of natural resources (Alonso and Guzmán, 2010). Generally, alternative farming systems contribute to an efficient use of fuels, mitigate the gas emissions and reduce the major impacts of climate change (IPCC, 2014).

In agriculture, the efficiency of water use is essential in developing sustainable production systems. Although there are studies exploring the multifaceted uses of inputs in farms (Michos et al., 2012; Abeliotis et al., 2013; Litskas et al., 2013; Kehagias et al., 2015), due to different farm production systems all over the world, more research is needed to deal with the gaps. The water footprint is an indicator of water use in relation to the production (Mekonnen and Hoekstra, 2010; Hoekstra et al., 2011). A water footprint is composed of three components: the green, blue, and grey water footprints. The grey water footprint designates the use of water derived from domestic wastewater. In many countries, wastewater is being investigated as an option for agricultural use (Maassen, 2016). The blue water footprint refers to the use of water from rivers, lakes, wetlands, and aquifers, while the green water footprint refers to the use of rainwater from croplands and grasslands. In mountainous areas with low availability of water, the green water footprint is a basic indicator for the water use from the crops (Hoekstra, 2014).

According to Pimentel et al. (2002), in developed countries, the energy use in food production represents a large percentage of energy consumption. Farming practices determine to a large extent the amount of energy inputs (e.g., fuels, water, and agrochemicals) used in crops. The preferred methodology for quantification of greenhouse gas emissions is LCA (Life Cycle Analysis; Adewale et al., 2016; Litskas et al., 2017). Energy and environmental analysis of farming systems could be combined to lead to the best management practices (Michos et al., 2012).

In Europe, grapevines (*Vitis vinifera* L.), kiwi (*Actinidia deliciosa* L.), and apples (*Malus domestica* Borkh.) represent 35.8%, 22.4%, and 20.7% of the world production, respectively (FAO, 2014). The production area and the annual production of each species are presented in Fig. 1. In Greece, the annual production of grape, kiwi, and apple is 1.05, 0.17, and 0.28 Mt, respectively, and corresponds to a production area of 111×10^3 (grapevines), 8×10^3 (kiwi orchards), and 12×10^3 (apple orchards) ha (FAO, 2014, Fig. 1).

Vineyards and kiwi and apple orchards are often a monoculture in mountainous areas, especially, in the northern part of Greece. In this area, farmers have been systematically occupied with grape, kiwi, and apple production since the second half of the 20th century. Low intensity farming systems, such as organic and integrated, can probably contribute in reducing production costs, using human labor efficiently, and protecting the environment (Michos et al., 2012; 2017; Zafiriou et al., 2012; Taxides et al., 2015). Energy inputs of crop production could determine which operations are using high amounts of energy (Reganold et al., 2001; Blanke and Burdick, 2005; Kehagias et al., 2015; Michos et al., 2017). Within the frame of this research, conventional and organic vineyards and kiwi orchards along with conventional, integrated and organic apple orchards in Pella Prefecture in northern Greece, were selected from sites located both in and out Natura 2000 network. The production area and the annual production of each species are presented in Fig. 1. The aims of the present study were to (a) determine energy efficiency of the farming systems, (b) estimate gas emissions, carbon and water footprint, and (c) reveal groups of farms on the basis of their similarities to energy efficiency, carbon and water footprint.

2. Materials and methods

2.1. Farm and site description

Forty one farms were selected in areas in the Prefecture of Pella, northern Greece, with proportional stratified random sampling during the years 2010–2014 (Appendix A). The vineyards were 15 [10 conventional (VC1, VC2, VC3, VC4, VC5, VC6, VC7, VC8, VC9, VC10) and five organic (VO1, VO2, VO3, VO4, VO5)]. The kiwi orchards were eight [five conventional (KC1, KC2, KC3, KC4, KC5) and three organic (KO1, KO2, KO3)]. The apple orchards were 18 [six conventional (AC1, AC2, AC3, AC4, AC5, AC6), four organic (AO1, AO2, AO3, AO4), and eight integrated (AI1, AI2, AI3, AI4, AI5, AI6, AI7, AI8)]. Seven vineyards, four kiwi orchards, and nine apple orchards were located in Natura (2000) sites (Habitats Directive 92/43/EEC, Directive, 2009/147/EC; MAP, 2017). Two of the selected Natura 2000 network vineyards were located in GR1240008 (Oros Voras; SDFV, 2017), four in GR1240004 (Lake Agra; SDFA, 2017) and one in GR1240009 (Oros Paiko, Stena Apsalou and Moglenitsas; SDFP, 2017). Four of the selected Natura 2000 network kiwi orchards were located in GR1240009 (Oros Paiko, Stena Apsalou and Moglenitsas; SDFP, 2017). Finally, nine of the selected Natura 2000 network apple orchards were located in GR1340004 (Lakes Vegoritida, Petron; SDFVP, 2017).

The selected farms represent the 10% of those located at the studied areas with an age of 12–18 years. At this age the studied species reach their maximum fruit production. The respective grapevine, kiwi and apple varieties were “Xinomavro”, “Hayword” and “Starking Delicious”. The size of all studied farms was about 0.8 ha. The plant density per ha ranged, from 2170 to 2800 grapevines, from 364 to 667 kiwi vines, and from 250 to 350 apple trees. All farms had moderate slopes (10–15%), were easily approached, and their altitude ranged from 10 to 640 m. The previous crops were other apple varieties and chestnut and sweet cherry trees. Organic farmers are applying the regulations EC 834/2007 and EC 889/2008. According to the Greek National Meteorological Service, the mean annual temperature, total annual precipitation, and mean annual relative humidity in the study area (mean ± SD; $n = 15$ years) were 15.5 ± 5 °C, 550 ± 29 mm, and 78 ± 20%, respectively.

2.2. Life cycle assessment

Energy indices were determined using an adjusted to agriculture Life Cycle Assessment (LCA) method (Finkbeiner et al., 2006; ISO, 2006a; b; Adler et al., 2007; Finnveden et al., 2009; Zafiriou et al., 2012; Taxidis et al., 2015), which involves the following four stages. In stage 1, the goals were a) to calculate the energy used, the water footprint, and the greenhouse gas emissions from fertilizers, soils, and fuels in vineyards, kiwi and apple orchards, and b) to compare them in order to determine the species or farming system with the lowest energy inputs, water footprint, and gas emissions. The functional unit was the grape, kiwi, and apple production per ha. The system boundaries started at the production and the application of fertilizers and pesticides, the manufacturing agricultural tools and machines, the soil preparation etc, and ended at the removal of the grapevine, kiwi, and apple fruit production from the farm in order to be stored, sold, processed etc. In stage 2, the energy inputs and outputs of the farming systems along with water footprint, and the greenhouse gas emissions for fertilizers, soils, and fuels were calculated. In stage 3, the effects of the farming systems on the grape, kiwi, and apple yields, the water footprint, and the greenhouse gas emissions were defined. In stage 4, the results were evaluated and discussed.

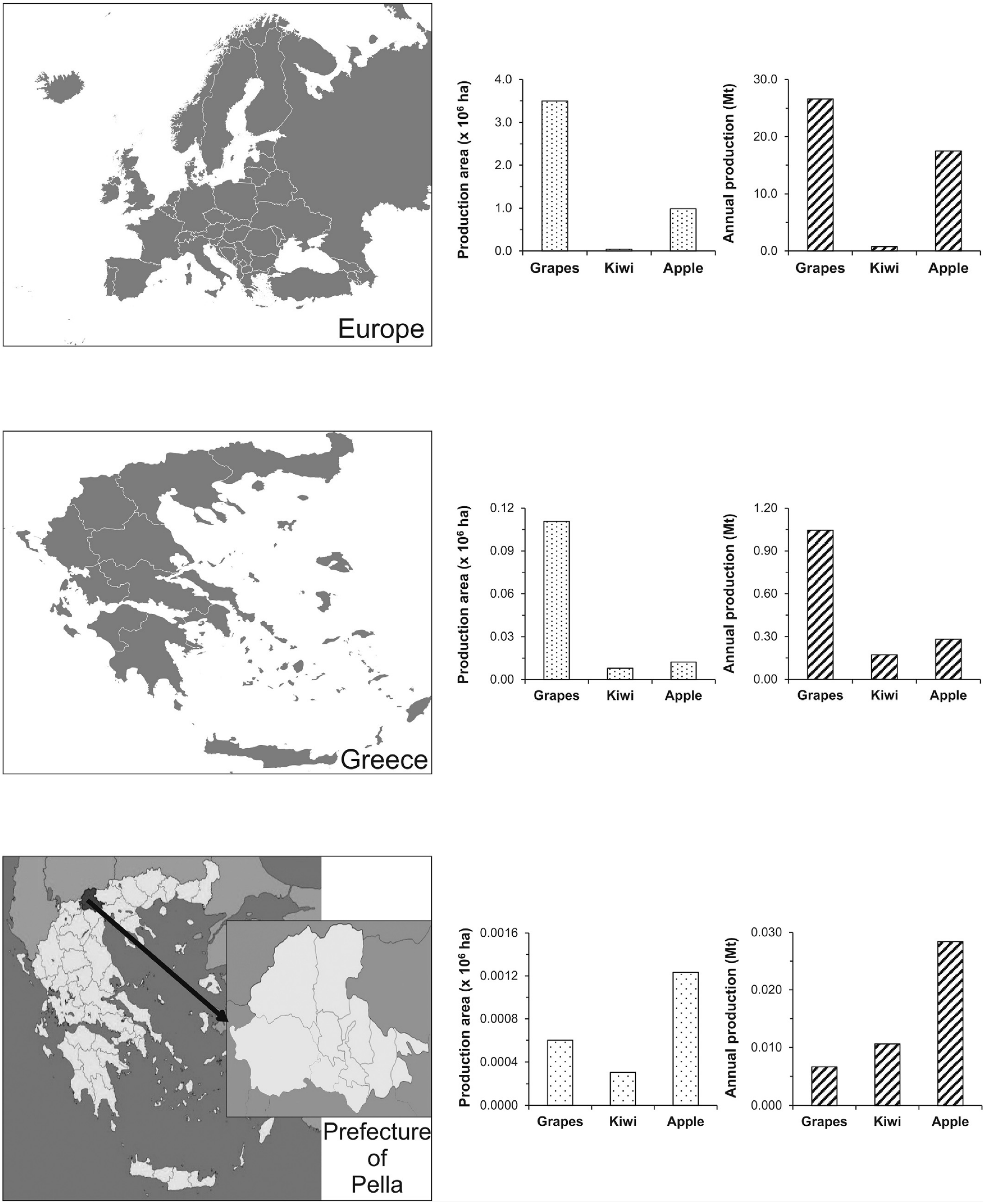

Fig. 1. Grape, kiwi, and apple production area with corresponding annual production in Europe, Greece and Pella Prefecture.

2.3. Energy content

Appendixes B and C present the farm management practices for vineyards, kiwi and apple orchards in each farming system during the study period. The crop encapsulates energy, which was estimated using the farmers' work-plan, the duration of each operation, the number of machines and laborers, field operation inputs (e.g. irrigation and pesticide application), and production coefficients (e.g. fuels and fertilizers). The above mentioned energy was enumerated by recording material used, fuel consumption, and the duration of each operation. The machinery embodied energy was determined using the coefficients in Appendix D. The machinery structure materials embodied energy equal to 142.7 MJ kg^{-1} (Pimentel et al., 1973; Fluck, 1985, 1992). This is composed of manufacture energy (86.40 MJ kg^{-1} of mass; Pimentel et al., 1973), repairs and maintenance energy (0.55 times the manufacture energy; Fluck, 1985), and transportation energy (8.80 MJ kg^{-1}; Bridges and Smith, 1979). Each machinery, when used for the first time, has a total embodied energy, which is the product of 142.7 MJ kg^{-1} times the machinery's weight. The machinery can work for 2000–15,000 h. For every hour of the machinery life span, a portion of energy is "lost". This portion is equal to the ratio of the total embodied energy divided by its total life. The working hours of the machinery influence the loss of the initial embodied energy. Each operation requires energy which derives from the sum of the embodied energy and the energy of human labor and fuel. Conventional agriculture is usually intensive and this creates a major threat to the environment. This threat is expected to be lower in integrated and organic agriculture. Energy inputs of fuels, chemical fertilizers, pesticides, human labor, and animal manure are the components of total energy inputs.

2.4. Carbon and water footprint

The used fossil fuel was determined by the diesel litres that refilled the reservoir of machinery used for farm operations (e.g. application of fertilizers, weed control, insecticides, and fungicides). Carbon dioxide, CH_4, and N_2O emissions were estimated for all cultivation practices (IPCC, 1997, 2006; ISO, 2013; Pandey and Agrawal, 2014), for fertilizers (IPCC, 1997; EMEP/EEA, 2009), for soils (Küstermann et al., 2008), and for fuel (IPCC, 1997, 2006). According to IPCC (2014) fertilizers (mainly nitrogen), soils, and fuels, are the largest contributors to global warming potential in crop production. The greenhouse gas emission equivalents for fertilizers (based on their composition), soils, and fuels are shown in Appendix E.

The water footprint of crops (cm^3 kg^{-1}) is calculated by dividing the total volume of green and blue water used (cm^3 yr^{-1}) by the quantity of the production (kg yr^{-1}) (Mekonnen and Hoekstra, 2010; 2013; ISO, 2014).

2.5. Statistical analyses

The Hierarchical Cluster Analysis (HCA) method was applied using three environmental indices (energy efficiency, CO_2-equivalent per fruit production, and water consumption per fruit production) in order to reveal groups of farming systems (Michos et al., 2012; Zafiriou et al., 2012; Litskas et al., 2013; Taxidis et al., 2015). Ward's minimum variance criterion (Ward, 1963) was used for cluster formation. The dissimilarity between the studied orchards was measured with the squared Euclidian distance (Sharma, 1996). The significance, from a statistical point of view, of the revealed clusters was tested with the moving average criterion (Mojena and Wishart, 1980). The contribution of each production coefficient in cluster configuration was assessed by the size and the significance of the corresponding R^2 indices. Before running HCA, the values (X) of the three environmental indices were log (X+1) transformed for a) smoothing and homogenizing skewed variables' distribution which contained a lot of zero values (Mucha et al., 2008) and b) validating the statistical significance of R^2 indices. A number of Mann-Whitney (M-W) tests were accomplished in order to examine the pair-wise differences between clusters concerning the untransformed production coefficients' and external variables which were not entered in the cluster analysis. M-W tests were performed only in cases where an omnibus Kruskal-Wallis (M-W) test showed significant differences. The observed significance level (P-value) in all M-W tests was computed by the Monte-Carlo simulation method (Mehta and Patel, 1996) using 10,000 random samples in each case. HCA was accomplished with SPSS ver.15.0 and Clustan ver.5.27 (the latter used for testing the significance of the cluster solution). Input order stability and validity of the resulted cluster solution was tested and verified through a bootstrap procedure (Spaans and Van der Kloot, 2004) supported by

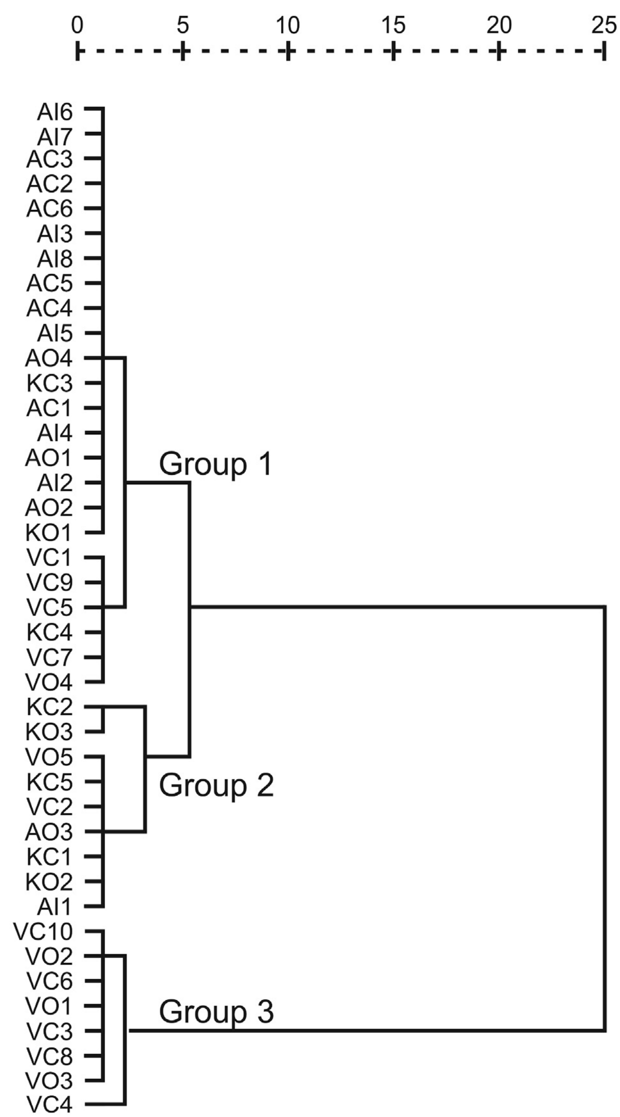

Fig. 2. Dendrogram of hierarchical cluster analysis (HCA). Conventional (VC1, VC2, VC3, VC4, VC5, VC6, VC7, VC8, VC9, VC10) and organic (VO1, VO2, VO3, VO4, VO5) vineyards; Conventional (KC1, KC2, KC3, KC4, KC5) and organic (KO1, KO2, KO3) kiwi orchards; Conventional (AC1, AC2, AC3, AC4, AC5, AC6), organic (AO1, AO2, AO3, AO4), and integrated (AI1, AI2, AI3, AI4, AI5, AI6, AI7, AI8) apple orchards.

Table 1
Group means (untransformed values) relative to environmental indices and the respective R^2 coefficients derived from transformed data. Means in the same row followed by different exponential letters are statistical significantly different.

Environmental indices	Group 1 ($n = 24$)	Group 2 ($n = 9$)	Group 3 ($n = 8$)	R^2	P
Energy efficiency[a]	1.13^{b}	0.29^{a}	0.16^{a}	**0.731**	**<0.001**
CO_2-equivalent per fruit production (kg kg^{-1})	0.08^{a}	0.45^{b}	3.74^{c}	**0.880**	**<0.001**
Water consumption per fruit production (cm^3 kg^{-1})	0.13^{b}	0.58^{c}	0.08^{a}	**0.276**	**0.002**

[a] Energy outputs/total energy inputs.

PermuCLUSTER ver.1.0 (an SPSS addin). Rank order similarities among the resulted clusters, relative to external inputs variables, were examined by computing and evaluating the corresponding Spearman's *rho* correlation coefficients. Finally, the Discriminant Analysis (DA) method (Klecka, 1980; Hair et al., 2010) was applied for testing in what extent linear combinations of the three indices (energy efficiency, CO_2-equivalent per fruit production, and water consumption per fruit production) could be used as predictors of the groups of farming systems resulted from the HCA. Discriminant functions' coefficients were estimated with the bootstrap method (based on 1000 samples). The SPSS ver.23 software was used for the implementation of DA. Significance level in all statistical tests was preset at $a = 0.05$.

3. Results

3.1. Parameters of energy balance

Hierarchical Cluster Analysis revealed three groups of the studied farms (Fig. 2). The moving average criterion showed that the three cluster solution was significant (t (39) = 6.21, $P < 0.001$). The cophenetic correlation coefficient having high value ($r_c = 0.77$, $P < 0.001$) verifies that the dendrogram in Fig. 2 preserves almost exactly the original pair-wise distances. Table 1 gives the centroids for each group relative to environmental indices. In descending order, the contributors in cluster formation were CO_2-equivalent per fruit production, energy efficiency, and water consumption per fruit production. This is clear from their relative and significant ($P < 0.001$) R^2 values (Table 1). Group 1 [all apple orchards except of AO3 and AI1, three kiwi orchards (KC3, KC4, KO1) and five vineyards (VC1, VC5, VC7, VC9, and VO4)] had statistically significant higher energy efficiency than Groups 2 and 3 (Table 1; Fig. 3). Mean values for CO_2-equivalent per fruit production of Group 3 [eight vineyards (VC3, VC4, VC6, VC8, VC10, VO1, VO2, and VO3)] were significantly high, intermediate for Group 2 and low for Group 1 (Table 1; Fig. 3). Mean values for water consumption per fruit production were significantly high for Group 2 [five kiwi orchards (KC1, KC2, KC5, KO2, KO3), two apple orchards (AO3, AI1) and two vineyards (VC2, VO5)], intermediate for Group 1, and low for Group 3 (Table 1; Fig. 3).

Appendix F presents the squared Euclidian distances (di) among the 41 farms, ranging from 0.001 to 0.524 for Group 1, from 0.005 to 0.388 for Group 2, and from 0.001 to 0.344 for Group 3. The vineyards VC4 and VO4 are the most dissimilar (di = 1.216). Fig. 2 shows that Group 3 (VC3, VC4, VC6, VC8, VC10, VO1, VO2 and VO3) was the most homogeneous cluster. Group 1 consists of two sub-clusters. One sub-cluster includes AC1, AC2, AC3, AC4, AC5, AC6, AO1, AO2, AO4, AI2, AI3, AI4, AI5, AI6, AI7, AI8, KC3, and KO1, and the second

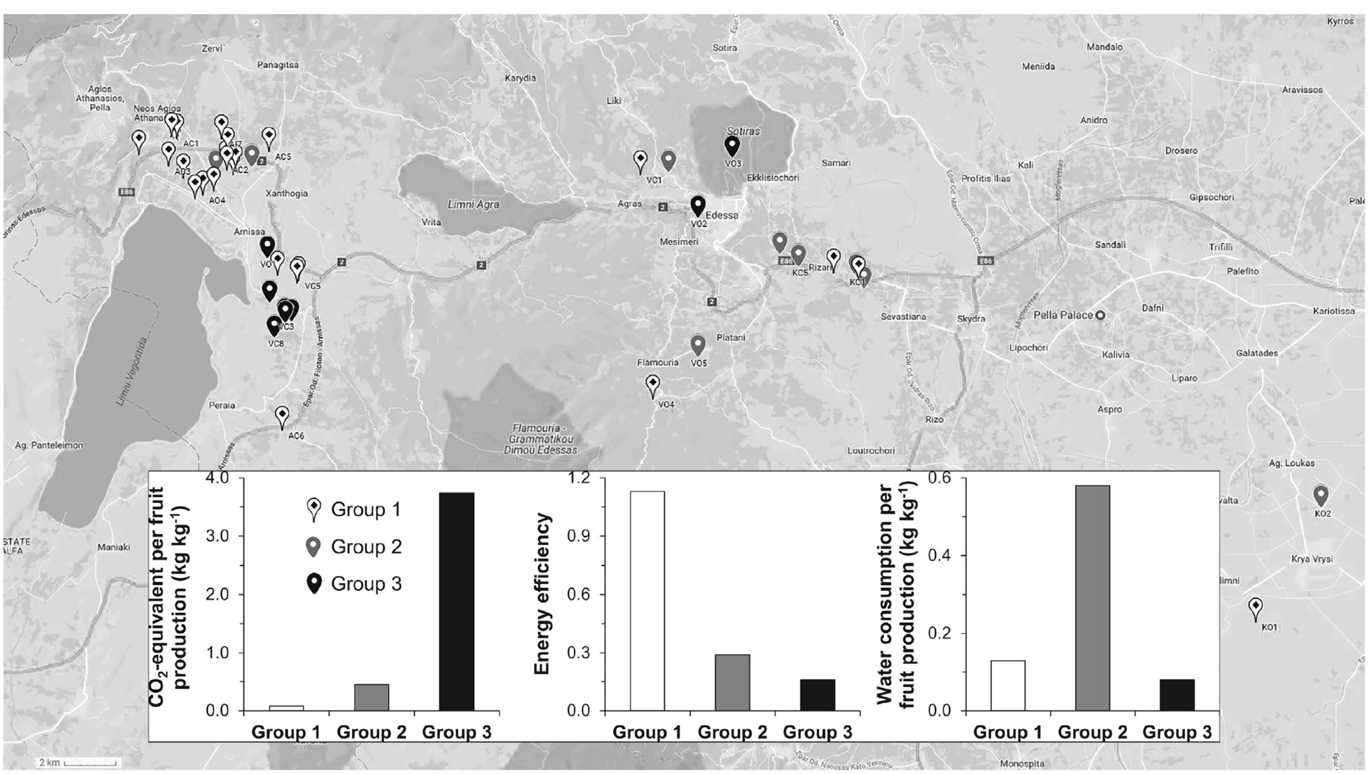

Fig. 3. Map and respective environmental indices (means) per group of selected vineyards and apple and kiwi orchards in Prefecture of Pella.

Table 2
Comparisons of the three Groups, relative to their mean values of 19 external variables. Mean values in the same row followed by different exponential letters are statistical significantly different.

Variables	Group 1	Group 2	Group 3	M-W(*P*)[a]
Altitude (m)	492.0[b]	252.7[a]	522.5[b]	**0.012**
Labor (MJ ha^{-1})	1327.5[a]	1215.2[a]	2434.2[b]	**0.019**
Diesel (MJ ha^{-1})	23,635.8[a]	27,133.0[a]	54,956.7[b]	**0.003**
Machinery (MJ ha^{-1})	7368.2[a]	6607.4[a]	11,457.2[a]	0.514
Fertilizers (MJ ha^{-1})	15,575.2[a]	14,269.6[a]	6599.0[a]	0.290
Fungicides (MJ ha^{-1})	569.5[b]	258.4[a]	185.3[a]	**0.004**
Insecticides (MJ ha^{-1})	869.9[a]	418.5[a]	215.7[a]	0.063
Weed control (MJ ha^{-1})	655.4[c]	7.96[a]	78.4[b]	**0.004**
Irrigation (MJ ha^{-1})	25,024.2[b]	29,797.0[b]	4556.2[a]	**0.018**
Branches shoring (MJ ha^{-1})	589.0[a]	1580.7[b]	3036.8[c]	**<0.001**
Total energy inputs (MJ ha^{-1})	75,614.6[a]	81,287.6[a]	83,519.5[a]	0.966
Energy outputs (MJ ha^{-1})	72,153.5[c]	17,577.1[b]	9535.0[a]	**<0.001**
Energy productivity[b] (kg MJ^{-1})	0.41[c]	0.11[b]	0.02[a]	**<0.001**
Intensity[c] (MJ kg^{-1})	0.99[a]	6.82[b]	15.52[c]	**<0.001**
Energy consumption[d] (MJ kg^{-1})	2.87[a]	15.0[b]	78.77[c]	**<0.001**
CO_2 (Mg ha^{-1})	1.75[a]	2.01[a]	4.07[b]	**0.003**
CH_4 (kg ha^{-1})	0.24[a]	0.27[a]	0.55[b]	**0.003**
N_2O (kg ha^{-1})	0.14[a]	0.16[a]	0.33[b]	**0.003**
Total water consumption (m^3 ha^{-1})	4297.5[b]	4000.0[b]	60.0[a]	**0.002**

[a] M-W(*P*) = *P*-value from Kruskal-Wallis test.
[b] The ratio of fruit produced to the energy inputs in production.
[c] The reciprocal of energy productivity.
[d] Energy inputs/fruit production.

includes KC4, VC1, VC5, VC7, VC9, and VO4 (Fig. 2). Group 2 consists of two sub-clusters. One includes AO3, AI1, KC1, KC5, KO2, VC2, and VO5, while the other KC2, and KO3.

The most important production coefficients in Group 1 were irrigation (33.1%), fuels (31.2%), fertilizers (20.5%), machinery (9.7%), and labor (1.8%). In Group 2, the ordering pattern of production coefficients was irrigation (36.7%), fuels (33.4%), fertilizers (17.8%), machinery (8.1%), branches shoring (1.9%), and labor (1.5%). In Group 3, the ordering pattern of production coefficients was fuels (65.8%), machinery (13.7%), fertilizers (7.9%), irrigation (5.5%), branches shoring (3.6%), and labor (2.9%). External inputs variables were similarly ranked within each group. The values of the corresponding Spearman's rank correlation coefficients were the following: between Group 1 and Group 2 ($rho = 0.85$, $P < 0.01$), between Group 1 and Group 3 ($rho = 0.73$, $P < 0.05$), and between Group 2 and Group 3 ($rho = 0.88$, $P < 0.01$).

Table 2 presents the comparison of the three groups, relative to their mean values of 19 external variables. Altitude was the lowest for Group 2 (Table 2). Labor and diesel were the highest in Group 3 (Table 2). Fungicides were the highest for Group 1, while for Group 3 were the lowest (Table 2). Group 2 showed the lowest weed control, while Group 1 the highest (Table 2). Irrigation and total water inputs were the lowest in Group 3 (Table 2). Branches shoring, intensity and energy consumption were the lowest in Group 1, intermediate in Group 2, and high in Group 3 (Table 2). Finally, mean values for energy outputs and energy productivity were significantly low in Group 3, intermediate in Group 2 and high in Group 1 (Table 2).

3.2. Greenhouse gas emissions

Greenhouse gas emissions of vineyards, apple and kiwi orchards were estimated for fertilizers, soils, and fuels (the largest contributors). Carbon dioxide, CH_4, and N_2O emissions were the highest for Group 3 (VC3, VC4, VC6, VC8, VC10, VO1, VO2, and VO3) and low for the other two Groups (Table 2).

3.3. Canonical discriminant function coefficients

According to DA results the two discriminant functions are:

$$F_1 = -0.202 + 6.949_* EE - 10.014_* CF + 6.072_* WF \quad (1)$$

$$F_2 = -2.913 + 10.918_* EE + 4.397_* CF - 4.077_* WF \quad (2)$$

Where EE corresponds to the energy efficiency, CF is the CO_2-equivalent per fruit production (kg kg^{-1}) and WF is the water consumption per fruit production (cm^3 kg^{-1}). The first dimension (Function 1) explains the 91.3% of the total variance and the second (Function 2) the remaining 8.7%. The two functions were statistically significant at $P < 0.001$. The cross validation of the proposed model {functions [1] and [2]} showed a 100% of correct classification. The first dimension is mainly associated with CO_2-equivalent per fruit production. The second dimension is mainly associated with energy efficiency and water consumption per fruit production. Fig. 4 depicts the projection of the farming systems and their groupings on the discriminant functions' plane. In Table 3 the discrimination functions' coefficients are presented along with the corresponding 95% bootstrap confidence intervals.

4. Discussion

4.1. Parameters of energy balance

Hierarchical cluster analysis revealed three groups of the studied farming systems. Group 1 (mainly apple orchards) was related with high values of energy efficiency. Analogous results have been reported by other researchers (Funt, 1980; Reganold et al., 2001; Blanke and Burdick, 2005; Kehagias et al., 2015). All groups showed energy efficiency lower than olive groves (Kaltsas et al., 2007; Taxidis et al., 2015), but higher than white asparagus farms (Zafiriou et al., 2012). Group 2 (vineyards, kiwi and apple orchards) was related with high values of water consumption per fruit production. Finally, Group 3 (vineyards) was related with high values of CO_2-equivalent. The combination of the above mentioned three indices mainly affected the grouping of the studied farms, revealing their importance for the agricultural environment and that they can help to seek, which crop and farming system could be applied in sensitive sites for high environmental advantages. Group 1 showed high environmental advantages since it had the highest energy

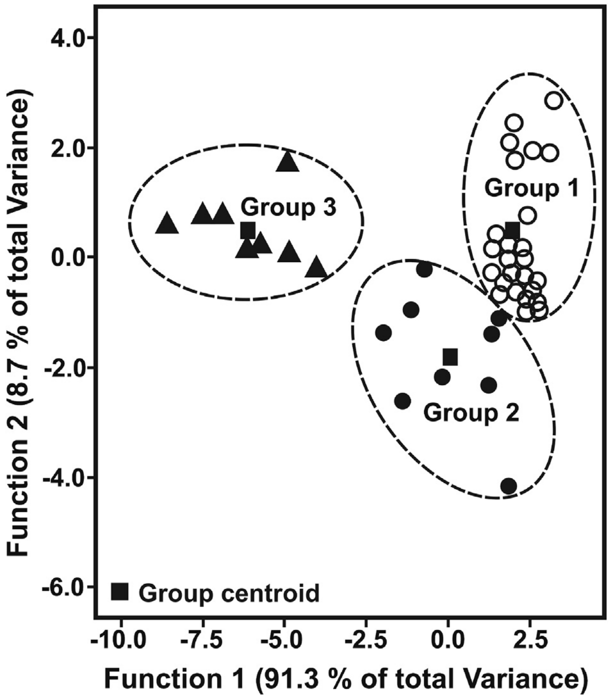

Fig. 4. Canonical discriminant function.

Table 3
Discrimination functions' coefficients are presented along with the corresponding 95% bootstrap confidence intervals.

	Discrimination functions (constant & variables)	Coefficients	BC[a] 95% confidence interval	
			Lower	Upper
F_1	Constant	−0.202	−1.740	1.336
	Efficiency	6.949	5.411	8.487
	CO_2-equivalent/fruit production (kg kg^{-1})	−10.014	−11.552	−11.552
	Water/fruit production (cm^3 kg^{-1})	6.072	4.534	7.609
F_2	Constant	−2.913	−3.557	−2.268
	Efficiency	10.918	10.273	11.562
	CO_2-equivalent/fruit production (kg kg^{-1})	4.397	3.752	5.041
	Water/fruit production (cm^3 kg^{-1})	−4.077	−4.722	−2.540

[a] Bias Corrected Bootstrap Confidence Interval.

efficiency, intermediate requirements of water consumption per fruit production, and the lowest CO_2-equivalent per fruit production.

Altitude, a topographic factor, could be an important issue for the present study. The vineyards of Group 3 located at the highest altitude resulted in highest labor, diesel, branch shoring, intensity and energy consumption. On the other hand they had the lowest irrigation, total water inputs, energy outputs, and energy productivity. Altitude, being a topographic factor, is important and along with the farm distance from farmers' house could play a role in farm grouping. Liu et al. (2010) reported that the performance of different farming systems was determined by site-specific factors, such as topography and farming practices. In the present study, the range of the most important production coefficients (inputs) was fuels (31.2–65.8%), fertilizers (7.9–20.5%), machinery (8.1–13.7%), irrigation (5.5–33.1%), and labor (1.5–2.9%). For other crops the major inputs were fuels (12–71%), fertilization (15–49%) and machinery (21–25%) (Strapatsa et al., 2006; Kaltsas et al., 2007; Pishgar-Komleh et al., 2012; Litskas et al., 2013). Carefully organized farming practices and topography may influence site functions and services, leading to high environmental advantages in the fragile equilibrium of Natura (2000) network.

4.2. Greenhouse gas emissions

In the present study, the largest contributors for the emission of CO_2-equivalents were fertilizers, soils, and fuels. Other researchers found that the largest contributors for greenhouse gas emissions were fertilizers, fuels and machinery in orange orchards (Nabavi-Pelesaraei et al., 2014), fuels in vineyards (Villanueva-Rey et al., 2014), fertilizers in pear orchards (Liu et al., 2010), and mechanization and fertilizers in apple orchards (Milà i Canals et al., 2006). Organic farming with low inputs can minimize greenhouse gas emissions, since the use of fuel and fertilizers are usually less (Kaltsas et al., 2007; Kavargiris et al., 2009; Raviv, 2009; Litskas et al., 2011; 2013; Kehagias et al., 2015; Taxidis et al., 2015). Organic farms apply best management practices by introducing the use of energy inputs such as human labor and animal manure and diminishing CO_2, CH_4, and N_2O-emissions. Khoshnevisan et al. (2013) related energy inputs of wheat production to CO_2, CH_4, and N_2O-emissions. In the present study, Group 1 (mainly apple orchards with high altitude) has the lowest carbon footprint (0.08 kg CO_2-equivalents produced 1 kg fruit) meaning that it has high environmental advantages.

4.3. Canonical discriminant function coefficients

The first dimension, explaining the 91.3% of the total variance, is mainly associated with CO_2-equivalent per fruit production. The second dimension, explaining the 8.7% of the total variance, is mainly associated with energy efficiency and water consumption per fruit production. The CO_2-equivalent per fruit production can discriminate the three Groups. It is a strong predictive factor especially for the Groups consisting of all type farms (apple and kiwi orchards and vineyards), regardless whether they are inside or outside Natura 2000 sites. The proposed discriminant analysis model could discriminate new farms showing environmental advantages.

5. Conclusions

In descending order, the contributors for farms' clustering were CO_2-equivalent, energy efficiency, and water footprint, leading to three Groups for vineyards and kiwi and apple orchards both in and out Natura 2000 network. Group 1 (mainly apple orchards) had the highest energy efficiency. Group 3 (vineyards) had the highest CO_2-equivalent per fruit production. Group 2 (vineyards, kiwi and apple orchards) had the highest water consumption per fruit production. Non-parametric comparisons revealed that most of external variables had statistically significant differences among the three Groups. The vineyards of Group 3 located at the highest altitude resulted in the highest labor, diesel, branch shoring, intensity and energy consumption. On the other hand they had the lowest irrigation, total water inputs, energy outputs, and energy productivity. Discriminant analysis showed that of the three indices (CO_2-equivalent, energy efficiency, and water footprint) CO_2-equivalent per fruit production was a strong predictive factor for the grouping of the farms. Group 1 (mainly apple orchards) has the lowest carbon footprint (0.08 kg CO_2-equivalents produced 1 kg fruit), intermediate water footprint (0.13 cm^3 kg^{-1}) and the highest energy efficiency (1.13). This means that Group 1 has high environmental advantages. It seems that the three indices (energy efficiency, carbon and water footprint) are very important for the agricultural environment and can help decision makers to seek crops and farming systems in order to regulate the fragile balance between Natura 2000 network and agriculture. The role of agriculture on habitats of sensitive environments such as Natura 2000 network sites is a main issue. Intensification of agricultural production depends on high inputs and leads to high greenhouse gas emissions. The impacts of agriculture on the climate change and the environment could be reduced by using less intensive and carefully organized farming practices.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jclepro.2018.03.251.

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