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Water-energy-food nexus: A case study on medicinal and aromatic plants

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ABSTRACT

Medicinal and Aromatic Plants (MAPs) are broadly cultivated in the Mediterranean but their environmental footprint is not very well studied. In this paper, Life Cycle Assessment (LCA) was applied to determine the energy balance, carbon and water footprints (CF and WF, respectively) in 50 farms, organic and conventional, where four MAP species were cultivated; spearmint (*Mentha spicata*), oregano (*Oreganum vulgare*), rosemary (*Rosmarinus officinalis*) and Damask rose (*Rosa damascena*). The lowest value for energy intensity (EI) was observed for organic spearmint (0.18 MJ/kg fresh weight; f.w.) while the highest for conventional Damask rose (5.80 MJ/kg f.w.). Statistically significant differences were observed in EI between organic and conventional farms for spearmint and Damask rose while no differences were found for oregano and rosemary. The lowest CF was observed for organic rosemary (0.051 kg CO_2-eq/kg f.w.) while the highest for conventional Damask rose (0.463 kg CO_2-eq/kg f.w.). Statistical differences in the CF between organic and conventional farms for the four species followed the same pattern as for EI. Conventional spearmint had the lowest WF (61.5 L of water/kg f.w.) and organic Damask rose the highest (1522 L of water/kg f.w.). Statistical differences between the two management systems were observed only for Damask rose. The 50 farms were grouped according to the values of three indicators (EI, CF and WF) using cluster analysis. Four clusters were identified with 68% of the farms (34) belonging to the low footprint cluster which contained organic and conventional spearmint, oregano and rosemary farms. The other three clusters contained the (16) Damask rose farms, where the inputs were higher in comparison to the other three species and the highest footprint clusters contained conventional rose farms. Our work suggests that MAPs are viable candidates for the implementation of sustainable agriculture in the Mediterranean.

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1. Introduction

The water-energy-food nexus is one of the most crucial for the sustainability of agriculture (Pelletier et al., 2011). Medicinal and Aromatic Plants (MAPs), also known as herbs or spices, are plants used for flavouring foods and beverages, in medicine, cosmetics, dye and perfume industry, among other uses. Global trade of MAPs as raw materials is estimated at 440,000 tons annually at a total value of 1.3 bn US dollars, of which 25% is marketed in Europe (Bogers et al., 2006; Máthé, 2015). In the European Union there are 65,000 ha of aromatic plant cultures (Lange, 2004; Barbieri, 2013). The main producers and exporters in Europe are Bulgaria, Turkey, Albania, Hungary, Poland, Czech Republic and Croatia. The main importers are Germany, France, Italy, Spain, Switzerland, Belgium and Luxemburg (Lange, 2004; Máthé, 2015). Currently, there is an increasing interest by the industry and academia on MAPs (Parejo et al., 2002; Raut and Karuppayil, 2014). Despite their economic and scientific importance, metrics of the environmental footprint of MAPs cultivation, such as the carbon footprint (CF), energy intensity (EI) and water footprint (WF), are less studied, in contrast to other important crops (Clune et al., 2017).

Agriculture impacts the climate system by contributing to greenhouse gas (GHG) emissions and the environment by using resources, such as water and fuels. Its global effects could be reduced by using less intensive farming practices (Litskas et al., 2013; Mekonnen and Hoekstra, 2014; Michos et al., 2018). The agricultural sector in the EU contributes 426.5 Mt of CO_2-equivalents (CO_2-eq) per year, excluding LULUCF (Land Use, Land Use Change and Forestry), equal to 10% of the EU total GHG emissions (Eurostat, 2017). Globally agricultural emissions are 20% of the total.

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They include fuel consumption in the farms, fertilizer production and application, soil N_2O emissions, enteric fermentation and manure degradation (Pachauri and Mayer, 2015). Low input farming may contribute to the reduction of the energy and resources for agricultural production, GHG emissions mitigation and carbon storage in the soils (Kehagias et al., 2015; Litskas et al., 2017) and protect the environment from deterioration (Alonso and Guzmán, 2010; Michos et al., 2018). The CF (kg CO_2-eq/kg of product) is an indicator of the impact that a product or activity has on the climate system. If the CF is determined for a product, management practices could be redesigned to reduce this impact, towards climate change mitigation (Hillier et al., 2011; Litskas et al., 2017). The CF has been already determined for various agricultural products and its value (kg CO_2-eq/kg) ranges from 0.04 for vegetables to 109.5 for beef meat (Clune et al., 2017).

Energy use for food cultivation and processing represents a large percentage of energy consumption in the developed and developing countries (Monforti-Ferrario et al., 2015). The farming methods and practices determine the energy inputs in agriculture (e.g. fuel, irrigation water, fertilizers production and distribution). Processing of raw materials to produce different kinds of food products as well as the transportation of food across the globe also add to the high energy consumption (Woods et al., 2010; Neira et al., 2016). The EI of a product is an indicator of the energy inputs required for agricultural production. Although this indicator is not as popular as the CF, it is quite useful for better management of the energy inputs. In studies on olive trees, vines and orchards in the Mediterranean, the reported values for EI range from 0.99 for indigenous vine varieties to 59 MJ/kg for intensively managed olive groves (Genitsariotis et al., 2000; Litskas et al., 2011, 2013; Michos et al., 2018).

In addition, agriculture is the larger user of water resources at a global scale (FAO/AQUASTAT, 2019). The efficient use of irrigation water is essential towards the sustainable use of this valuable resource, especially in arid areas such as the Mediterranean. The WF is a useful indicator, linked to the production of commodities (Mekonnen and Hoekstra, 2011, 2014). It involves three components; green, blue and grey water footprints. Green water is the water input from rainfall and blue is the amount of irrigation water (Mekonnen and Hoekstra, 2014). MAPs are well performers under water shortage due to their adaptation ecology. Recent work has shown that certain species of MAPs grown under water deficit exhibit increased essential oil yield/quality and improved antioxidant and insecticidal capacity, despite the decreased plant growth (Tzortzakis et al., 2011; Raut and Karuppayil, 2014; Chrysargyris et al., 2016). The WF of crops such as potatoes, rice and wheat is 224, 1486 and 1620 L/kg, respectively (Mekonnen and Hoekstra, 2011, 2014).

MAPs farming requires the use of inputs, such as fertilizers and pesticides, the use of materials and machinery, water resources (often non-renewable groundwater) and oil or natural gas to produce energy. Although MAPs are generally produced using low intensity agricultural practices, data on CF, EI and WF for MAPs are not currently available. The development of a knowledge base on CF, EI and WF for different MAPs can enhance the efficiency of the water – food – energy nexus, as it would enable the incorporation of efficiency metrics in the decision-making processes.

The preferred methodology for quantification of CF, EI and WF is LCA (Life Cycle Analysis; Litskas et al., 2017). This kind of analysis of farming systems could lead to the best management practices (Litskas et al., 2013; Michos et al., 2018). Accordingly, the aim of this research was to perform LCA to determine the CF, EI and WF of four important MAPs species: spearmint (*Mentha spicata*), oregano (*Oreganum vulgare*), rosemary (*Rosmarinus officinalis*) and Damask rose (*Rosa damascena*). The four selected MAPs are popular in the Mediterranean, as well as in other areas of the world.

2. Materials and methods

2.1. Selected farms and yield for the MAPs

Fifty (50) MAPs farms located in Cyprus were selected for the research (Fig. 1). Twelve of the farms were growing spearmint (6 organic vs. 6 conventional), 16 Damask rose (8 organic vs. 8 conventional), 12 oregano (6 organic vs. 6 conventional) and 10 rosemary (5 organic vs. 5 conventional). The average ($\pm$ 1 standard deviation; s.d.) size of the farms was 0.104 ($\pm$ 0.079) ha.

2.2. Life cycle assessment

Energy balance, CF and WF were determined using an LCA method adjusted to agriculture (ISO, 2006; Zafiriou et al., 2012; Michos et al., 2018). In this work, as well as in other relevant studies (e.g. Hillier et al., 2011; Clune et al., 2017; Michos et al., 2018) the functional units typically selected for agricultural products, regarding CF, EI and WF are: 1) 1 kg of product and 2) 1 ha of cultivated land. Therefore, the functional unit for the energy balance was energy use (MJ) per ha or kg of product while for CF, kg CO_2-eq/kg of product and kg CO_2-eq/ha (Hillier et al., 2011). For WF the functional unit was L of water/kg of product and m^3 of water/ha. The system boundaries started at the production and the application of fertilizers and pesticides, the manufacturing of agricultural tools and machines, the soil management practices, harvesting and ended at the gate of the merchants or factories that the farmers deliver their product. All indicators where expressed based on wet weight of the production for each species.

Inputs (e.g. fertilizers, pesticides, fuel, water, tools, machinery, labour) and outputs (e.g. fresh and dried product) were recorded with the use of a questionnaire that was built to conduct LCA. The 50 farmers and professionals that participated in the research were asked to provide data representative for the management practices for their farms during the period 2014–2017. Additional personal interviews with farmers (10), agronomists (5) and professionals (5) were also conducted for quality assurance regarding questionnaires results. In Appendices A-D (Supplementary Material), the recorded farm management practices for conventional and organic spearmint, Damask rose, oregano and rosemary are summarized.

2.3. Energy balance

The energy balance was based on 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 energy inputs and outputs were determined using the coefficients in Appendix E (Supplementary Material). The machinery structure materials embodied energy equal to 142.7 MJ/kg (Pimentel et al., 1973; Fluck, 1985; Litskas et al., 2013; Michos et al., 2018). This is composed of manufacture energy (86.40 MJ/kg of mass; Pimentel et al., 1973; Michos et al., 2018), repairs and maintenance energy (0.55 times the manufacture energy; Fluck, 1985), and transportation energy (8.80 MJ/kg; Pimentel et al., 1973; Michos et al., 2018). Each machinery, when used for the first time, has a total embodied energy, which is the product of 142.7 MJ/kg times the machinery's weight. The machinery can work for 2000–15000 h. Each operation requires energy which is derived from the sum of the embodied energy of the machine, and the energy of human labor and fuel. Energy inputs of fuels, chemical fertilizers, pesticides, human labour and animal manure are also components of the total energy inputs.

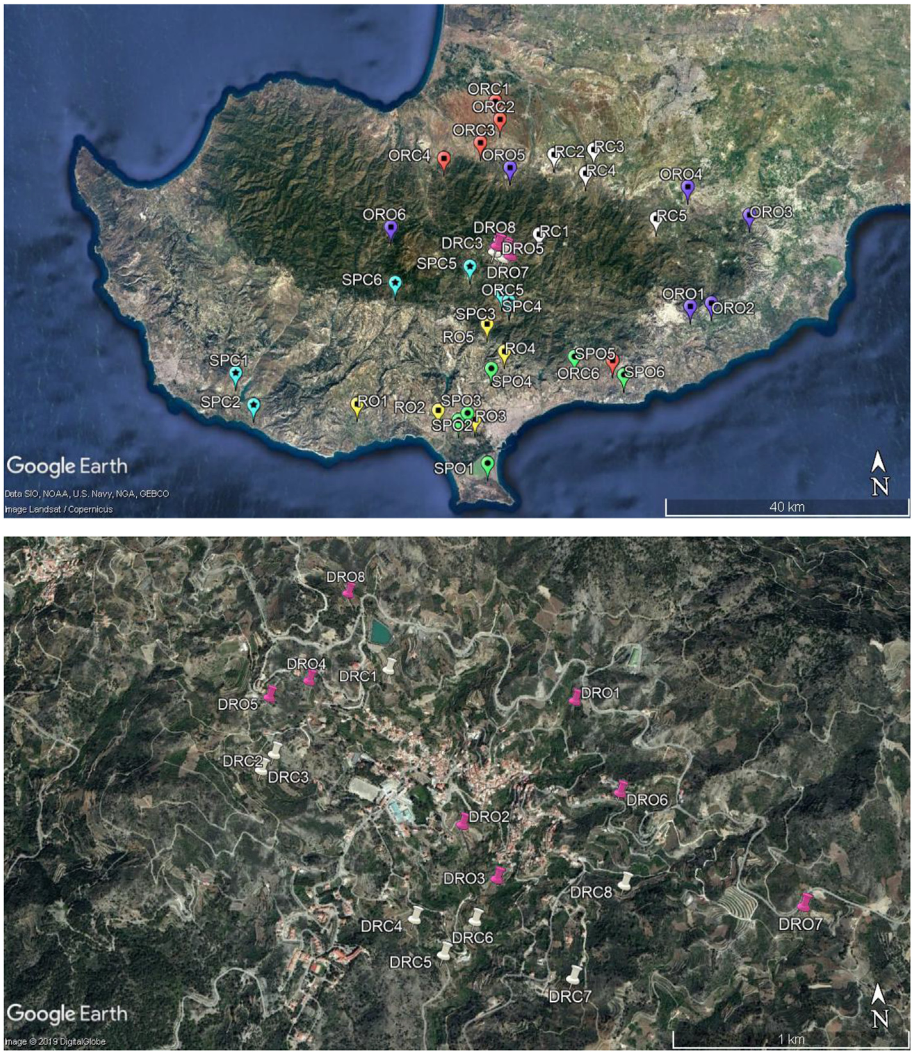

Fig. 1. Location of the MAP farms in Cyprus (up) and Damask rose farms that are in the area of Agros (down). SP, R, OR, DR stand for spearmint, rosemary, oregano, and Damask rose respectively; O and C stand for Organic and Conventional, respectively (e.g. SPO stands for spearmint organic).

2.4. Carbon and water footprint

The methodology that was followed for GHG emissions determination in the farms is presented in detail in previous studies (Bouwman et al., 2002; Hillier et al., 2011; Litskas et al., 2017; Michos et al., 2018). Biogenic emissions from N fertilizers applied in soil were accounted for in CF calculations, while sequestered C (due to organic fertilizers use) was considered to reduce the CF. The following factors were considered for emissions (kg CO_2-eq/kg or ha) calculation (Hillier et al., 2011): 1) Fertilisers: GHG emissions from the production and distribution of fertilisers; emissions due to the decomposition of manures/composts after their application to the field, 2) N_2O, NO and NH_3 soil emissions as a result of nitrogen fertilizer application and N transformation processes in soils, 3) Pesticide production and distribution 4) Crop residue management, 5) Carbon stock changes in the soil after organic matter amendments, 6) Field energy use for irrigation, pruning, tillage, pesticide and fertilizer application and 7) Off-farm transport (transportation to storage/market and annual trips of farmers to the fields). The system boundary for the study was from farm to factory door. Emission factors and additional information for the methodology used to calculate the GHG emissions are provided in Annex F (Supplementary material).

The water footprint of crops (L/kg) is calculated by dividing the total volume of green and blue water used (m^3/yr) by the quantity of the production (kg f.w./yr) (Mekonnen and Hoekstra, 2011; ISO 14046:2014) and it was also expressed as m^3/ha. Green water represents the amount of rain in the areas of the farms and the blue water the applied irrigation. The rainfall that was used for the calculations, was the average (2014–2017) that was recorded by the nearest meteorological station for each farm that participated in the research. The irrigation amount was provided from the records of the farmers participating in the research.

2.5. Statistical analyses

Summary statistics (average, standard deviation, coefficient of variation, standardized skewness and kurtosis) were calculated for the data using the STATGRAPHICS Centurion XVI (v. 16.1.11) software. Moreover, the Levene's test was performed to test for departures from the equality of variances between groups. A two-way ANOVA was used to test for the effect of species, cultivation system (organic vs. conventional) and their interaction on EI, CF and WF (three separate analyses). If the presence of a two-way interaction was detected, a one-way ANOVA was used to compare means between the two management systems within each crop. The Tukey's honestly significant difference (HSD) procedure was used for multiple comparisons at the 95% confidence level. The visualization of the results for the WF was done by constructing Tukey style Box-and-Whisker Plots as presented in Krzywinski and Altman (2014). The Hierarchical Cluster Analysis (HCA) method was applied using three environmental indices (EI, CF and WF) in order to reveal groups of farming systems (Litskas et al., 2013; Michos et al., 2018). Ward's minimum variance criterion was used for cluster formation. The dissimilarity between the studied orchards was measured with the squared Euclidian distance (Wilks, 2011).

3. Results

3.1. Yield for the MAPs

The average yield, kg fresh weight/ha in the organic and conventional farms is presented in Table 1. To reduce the variability, we used the average yield for the period 2014–2017, as provided by the growers and verified by experts. The average yield for the conventional aromatic plants farms was higher than that of the organic.

3.2. Energy balance

Table 2 shows the EI for organic and conventional MAP farms. There was a significant effect of species ($F_{3,42} = 61.69$; $P < 0.001$) and system ($F_{1,42} = 11.50$; $P = 0.015$).

The results of the one-way Anova detected a significantly lower EI value in organic vs. conventional spearmint farms ($F_{1,10} = 8.33$; $P = 0.016$). Lower energy values were observed in organic farms regarding machinery use in the field, fertilizers, pesticides, fuels, total inputs, outputs and EI. Energy input for irrigation was similar in the two management systems, while higher values in organic farms where observed for labour and energy use efficiency (Table 2).

For Damask rose (Table 2), significantly lower values in EI were observed in organic farms compared to the conventional ($F_{1,14} = 13.40$; $P = 0.026$). Lower energy utilization was observed for all components in the organic farms, but the output was similar between the two management systems. As a result, energy efficiency was substantially higher in the organic farms.

For oregano (Table 2), there were no differences between organic and conventional farms regarding EI ($F_{1,10} = 1.43$; $P = 0.26$). Lower values in energy use were observed in organic farms, in comparison to the conventional, for machinery, fertilizers, pesticides, irrigation, total inputs and outputs. Organic farms consumed higher amounts of energy for labour and fuel.

Finally, for rosemary (Table 2), EI did not differ significantly between organic and conventional farms ($F_{1,8} = 1.58$; $P = 0.24$). Higher energy values were recorded in conventional than in organic farms for machinery, fertilizers, pesticides, irrigation, fuel, input and output. Labour energy usage was higher in organic than in conventional. Energy efficiency was higher in organic than in conventional farms.

Table 1
Average (± 1 s.d.) yield (2014–2017) for the aromatic plants farms that were used in the study.

Management system	Fresh weight (kg/ha)
Organic	
Spearmint ($n = 6$)	64167 (±15943)
Damask Rose ($n = 8$)	3463 (±598)
Oregano ($n = 6$)	14750 (±2928)
Rosemary ($n = 5$)	20000 (±2550)
Conventional	
Spearmint ($n = 6$)	92500 (±5244)
Damask Rose ($n = 8$)	4750 (±598)
Oregano ($n = 6$)	19667 (±1366)
Rosemary ($n = 5$)	26400 (±4159)

3.3. Carbon footprint

CF values are presented in Table 3, expressed as kg CO_2-eq/kg f.w. of each product. This expression of emissions while the most popular, it depends on the yield which is variable for all the agricultural systems and is affected by factors such as, climatic parameters, soil type and plant variety. However, to provide an expression of the GHG emissions that will not depend on the yield, we also examined the GHG balance expressed as kg CO_2-eq/ha. The results for this approach are provided in Table 4.

There was a significant effect of species ($F_{3,42} = 66.53$; $P < 0.001$) and system ($F_{1,42} = 26.98$; $P < 0.001$) for the data presented in Table 3. However, if the same analysis is performed with the data of Table 4, where the CF is expressed as kg CO_2-eq/ha, there is a significant effect of system ($F_{1,42} = 200.15$; $P < 0.001$) but not of species ($F_{3,42} = 1.76$; $P < 0.170$). The results of the one-way Anova showed that the CF was higher in conventional than in organic spearmint farms ($F_{1,10} = 17.53$; $P = 0.002$). The same was observed when the emissions data were expressed per ha ($F_{1,10} = 184.33$; $P < 0.001$). The emissions were zero in the organic farms for pesticide and fertilizer use, while emissions for N_2O, field energy use and transportation were lower in organic than in conventional farms. Carbon sequestration because of the use of manure in organic farms further reduced the CF for spearmint. Carbon sequestration in the conventional farms was zero. The differences between the two management systems were also evident in the GHG emissions per ha (Table 4). Lower emissions were observed in all CF components in the organic vs. conventional farms.

The CF for Damask rose (Table 3) was significantly lower in organic than in conventional farms ($F_{1,14} = 35.45$; $P < 0.001$). Differences were also obvious when the CF was expressed per ha ($F_{1,14} = 170.84$; $P < 0.001$). The organic growers do not apply manure, therefore the emissions from fertilizers and N_2O are zero, as well as C storage (Table 3). Field energy use and pesticide related emissions were also lower in organic farms, while emissions due to residue management and transportation were higher in the organic farms. Emissions per land area (ha) were also lower in organic farms (Table 4).

The CF for oregano and rosemary (Table 3), was not significantly different between organic and conventional farms ($F_{1,10} = 1.15$; $P = 0.309$ and $F_{1,8} = 4.98$; $P = 0.056$), when the data were expressed as CO_2-eq/kg. However, significantly lower values were observed in the organic farms (Table 4) when the total emissions per ha were evaluated ($F_{1,10} = 12.2$; $P = 0.006$ and $F_{1,8} = 22.91$; $P = 0.001$). C storage further reduced the emissions in the organic vs. conventional oregano and rosemary farms (Tables 3 and 4).

3.4. Water footprint

When WF was expressed as L/kg (Fig. 2a), there was a significant effect of species ($F_{3,42} = 159.22$; $P < 0.001$) and system ($F_{1,42} = 5.85$; $P = 0.02$). The interaction was driven by a much lower total WF in conventional than in organic Damask rose, while the WF was similar between the two management systems for the other three species. Comparison of the total WF between organic and conventional spearmint with one-way ANOVA showed that there were no significant differences between the two systems ($F_{1,10} = 3.15$; $P = 0.106$). The blue and green WF was lower in conventional compared to the organic spearmint farms. The total WF for conventional Damask rose was significantly lower than that for organic

Table 2
Average values (± 1 standard deviation; s.d.) in MJ/ha for energy balance components, total input and output for each crop and management system. Efficiency (Outputs divided by Inputs) and Intensity (MJ/kg) indicators are also presented. Different lowercase letters within each crop indicate statistically significant differences ($P < 0.05$, Tukey HSD test after one-way Anova).

Crop	Management	Machinery	Labour	Fertilizers	Pesticides	Irrigation	Fuel Energy	Input	Output	Efficiency	Intensity
Spearmint	Organic ($n = 6$)	2758.0 (1112.7)	97.5 (21.9)	0	0	2050.3 (425.2)	6854.7 (1819.7)	11760.5 (2531.9)	118066.7 (29334.4)	10.04 (4.14)	0.18 [a] (0.07)
	Conventional ($n = 6$)	4861.2 (1257.1)	58.7 (31.4)	5795.8 (1935.2)	1049.8 (327.8)	2203.0 (449.7)	13130.0 (1197.6)	27098.5 (2184.6)	170200.0 (9649.0)	6.28 (0.82)	0.29 [b] (0.04)
Damask rose	Organic ($n = 8$)	2002.5 (1989.6)	35.6 (11.7)	0	1021.0 (373.1)	1640.8 (308.2)	6270.4 (2091.0)	10970.3 (1802.2)	19327.5 (1879.4)	1.76 (0.33)	3.17 [a] (0.69)
	Conventional ($n = 8$)	2738.4 (940.5)	92.4 (20.2)	4237.5 (1538.0)	1866.5 (277.0)	2054.1 (229.9)	16584.8 (3664.3)	27573.7 (5202.3)	18950.0 (6811.1)	0.69 (0.33)	5.80 [b] (1.99)
Oregano	Organic ($n = 6$)	6070.2 (2859.2)	334.4 (17.5)	0	0	1958.3 (897.0)	8456.2 (4434.5)	16819.1 (6667.9)	185407.5 (36808.9)	11.02 (7.38)	1.14 [a] (0.65)
	Conventional ($n = 6$)	10450.0 (2630.7)	75.2 (18.6)	5644.0 (794.7)	473.7 (123.1)	3274.2 (1041.3)	10977.5 (4394.6)	30894.6 (5293.6)	247210.0 (17173.9)	8.00 (1.99)	1.57 [a] (0.37)
Rosemary	Organic ($n = 5$)	8142.8 (6024.8)	237.2 (33.2)	0	0	1799.2 (571.9)	8353.0 (6213.5)	18532.2 (12521.5)	84000.0 (10707.9)	4.53 (3.53)	0.93 [a] (0.65)
	Conventional ($n = 5$)	10482.4 (6821.1)	81.0 (24.8)	7684.4 (2803.8)	685.6 (255.2)	3121.2 (1231.6)	13257.6 (4041.4)	35312.2 (8234.2)	110880.0 (17469.2)	3.14 (0.94)	1.34 [a] (0.36)

Table 3
Average values (± 1 s.d.) in kg CO_2-eq/kg product, are presented for different Carbon Footprint (CF) components for each crop and management system. Different lowercase letters within each crop indicate statistically significant differences ($P < 0.05$, Tukey HSD test after one-way Anova).

Crop	Management	Fertilizers[a]	N_2O	C sequestration	Pesticides	Field energy	Residue manag.	Transportation	CF
Spearmint	Organic ($n = 6$)	0	0.003 (0.001)	−0.0009 (0.0005)	0	0.0038 (0.0019)	–	0.0048 (0.0026)	0.0107 [a] (0.0054)
	Conventional ($n = 6$)	0.005 (0.002)	0.004 (0.001)	0	0.0013 (0.0004)	0.0040 (0.0013)	–	0.0066 (0.0020)	0.0209 [b] (0.0031)
Damask rose	Organic ($n = 8$)	0	0	0	0.01 (0.004)	0.13 (0.05)	0.012 (0.003)	0.014 (0.007)	0.166 [a] (0.050)
	Conventional ($n = 8$)	0.081 (0.032)	0.088 (0.019)	0	0.017 (0.008)	0.26 (0.1)	0.008 (0.005)	0.009 (0.008)	0.463 [b] (0.134)
Oregano	Organic ($n = 6$)	0	0.024 (0.007)	−0.0023 (0.0012)	0	0.01 (0.003)	–	0.037 (0.030)	0.069 [a] (0.037)
	Conventional ($n = 6$)	0.026 (0.005)	0.018 (0.003)	0	0.003 (0.002)	0.009 (0.003)	–	0.033 (0.018)	0.089 [a] (0.026)
Rosemary	Organic ($n = 5$)	0	0.023 (0.003)	−0.005 (0.002)	0	0.007 (0.003)	–	0.026 (0.023)	0.051 [a] (0.026)
	Conventional ($n = 5$)	0.026 (0.011)	0.017 (0.001)	0	0.002 (0.001)	0.005 (0.002)	–	0.033 (0.012)	0.083 [a] (0.021)

[a] For the conventional the emissions due to fertilizer production and distribution are provided here. The emissions from the application of fertilizers are incorporated in the field energy column.

Table 4
Average values (± 1 s.d.) in kg CO_2-eq/ha, are presented for CF (carbon footprint) components for each crop and management system.

Crop	Management	Fertilizers[a]	N_2O	C sequestration	Pesticides	Field energy	Residue mgmt	Transportation	CF
Spearmint	Organic ($n = 6$)	0	173.5 (40.0)	−60.8 (41.2)	0	229.2 (84.7)	–	281.7 (110.9)	623.6 (163.6)[a]
	Conventional ($n = 6$)	496.5 (171.7)	390.7 (57.0)	0	123.0 (36.7)	370.0 (113.3)	–	608.5 (169.2)	1988.7 (184.0)[b]
Damask rose	Organic ($n = 8$)	0	0	0	33.3 (15.3)	415.8 (168.8)	39.0 (7.3)	51.6 (40.2)	539.7 (154.2)[a]
	Conventional ($n = 8$)	377.4 (140.8)	408.1 (70.5)	0	77.0 (23.8)	1194.9 (270.4)	38.5 (29.4)	41.4 (38.5)	2137.3 (309.4)[b]
Oregano	Organic ($n = 6$)	0	346.5 (46.6)	−38.0 (18.2)	0	141.3 (54.7)	–	489.2 (344.6)	939.0 (371.4)[a]
	Conventional ($n = 6$)	509.7 (71.8)	344.5 (46.6)	0	48.0 (28.1)	176.7 (54.7)	–	642.0 (312.0)	1720.9 (403.9)[b]
Rosemary	Organic ($n = 5$)	0	445.2 (53.1)	−90.2 (31.1)	0	127.2 (47.4)	–	495.6 (428.4)	977.8 (472.0)[a]
	Conventional ($n = 5$)	651.6 (214.2)	447.2 (53.1)	0	57.6 (17.2)	148.4 (58.1)	–	861.2 (289.1)	2166.0 (280.4)[b]

[a] For the conventional the emissions due to fertilizer production and distribution are provided here. The emissions from the application of fertilizers are incorporated in the field energy column.

($F_{1,14} = 8.18$; $P = 0.013$). The green and blue WF were higher in organic compared to the conventional Damask rose farms. Differences in total WF between organic and conventional oregano and rosemary were not statistically significant ($F_{1,10} = 0.46$; $P = 0.511$ and $F_{1,8} = 0.21$; $P = 0.660$, respectively).

In the case where WF was expressed as m^3/ha (Fig. 2b), there was a significant effect of system ($F_{1,42} = 19.28$; $P < 0.001$) but not species ($F_{3,42} = 1.20$; $P = 0.33$). Comparison of the total WF between organic and conventional spearmint, Damask rose, and oregano with one-way ANOVA showed that there were significant differences between the two systems ($F_{1,10} = 6.05$; $P < 0.05$; $F_{1,14} = 9.24$; $P < 0.001$; $F_{1,10} = 6.00$; $P < 0.05$, respectively). No significant differences for the WF were found between organic and conventional rosemary farms ($F_{1,8} = 3.5$; $P > 0.05$).

3.5. Cluster analysis

Four clusters were identified in the analysis which was based on EI, CF per kg of product and total WF (Fig. 3). The centroids for the first cluster were 0.92 MJ/kg, 212.4 L/kg and 0.05 kg CO_2-eq/kg, for EI, WF and CF, respectively. For the second cluster, the values were 3.27 MJ/kg, 1522.3 L/kg and 0.16 kg CO_2-eq/kg, for EI, WF and CF, respectively. Regarding the third cluster, the values 5.35 MJ/kg, 1066.6 L/kg and 0.42 kg CO_2-eq/kg were obtained for EI, WF and CF, respectively. The fourth cluster had values of 10.5 MJ/kg, 1457 L/kg and 0.72 CO_2-eq/kg for EI, WF and CF, respectively. The first cluster contained 68% of the farms ($n = 34$), which were organic and conventional spearmint, oregano and rosemary, the second 16% ($n = 8$), the organic Damask rose farms, while the third 14% ($n = 7$) and the fourth 2% ($n = 1$) contained the conventional Damask rose farms.

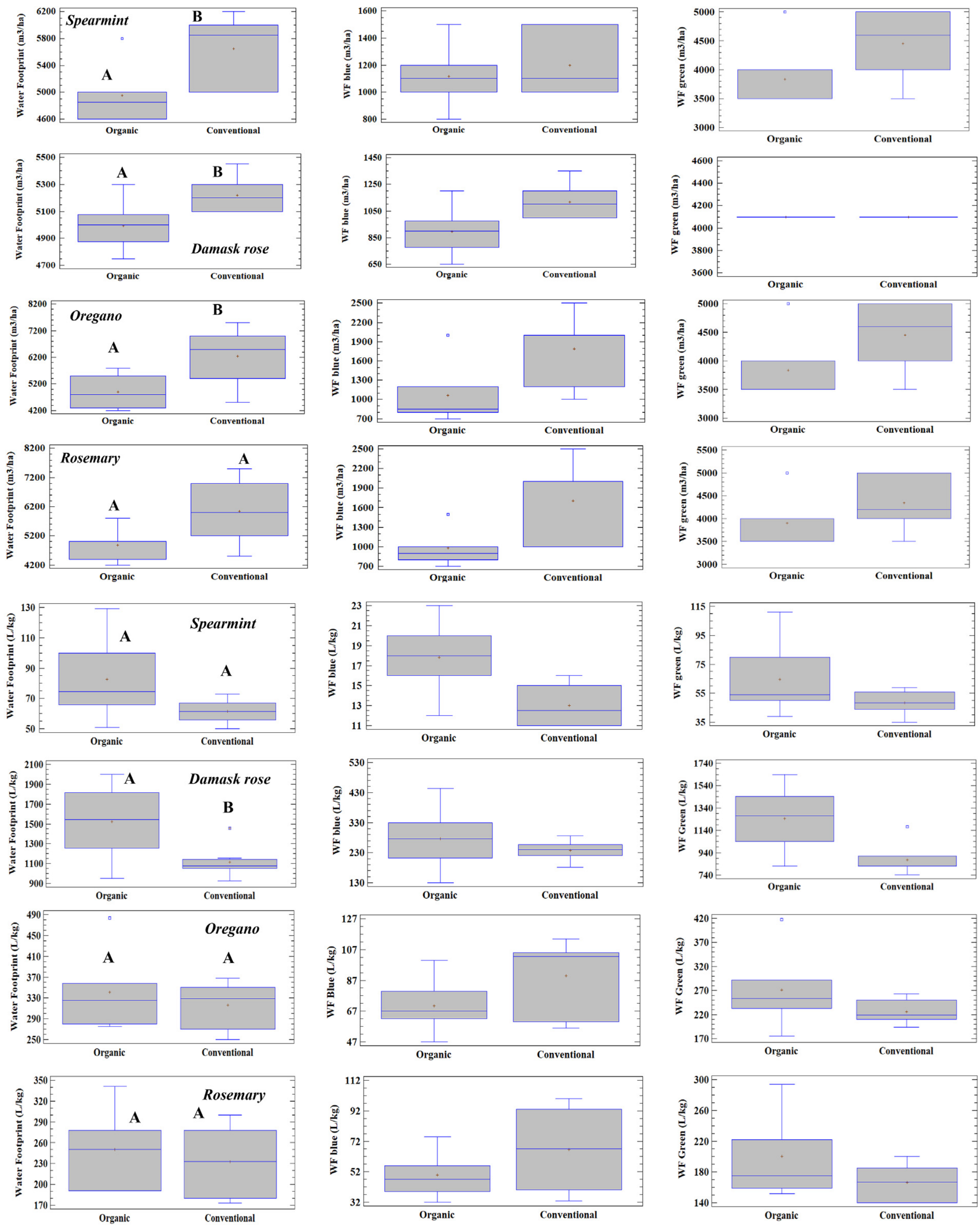

Fig. 2. a) Water footprint (total, blue, green) for organic and conventional aromatic plants, expressed as L per kg (f.w.) of produce. b) the water footprint expressed as m^3/ha. The box extends from the 25th to the 75th percentile, the horizontal line inside the box shows the median (in some cases it coincides with the 25th or the 75th percentiles), and the cross the mean. Whiskers extend at 1.5 times the interquartile range with outliers (if present) plotted as open squares. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

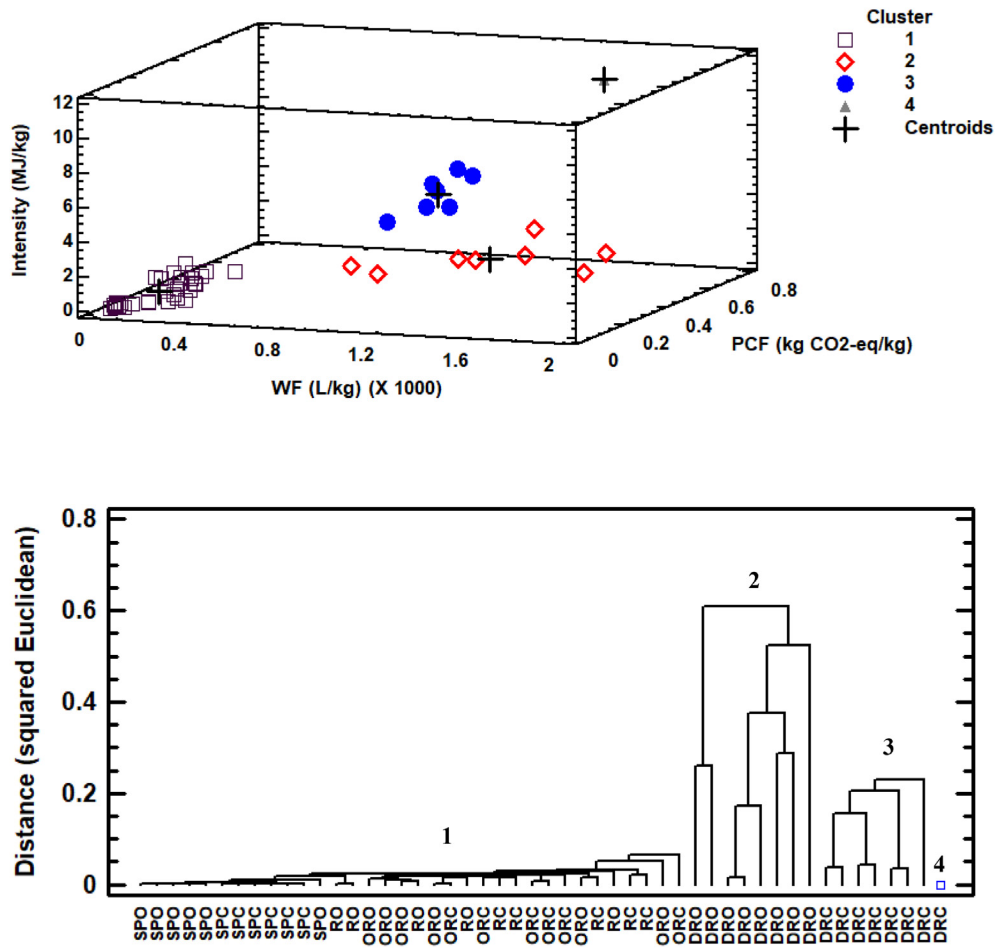

Fig. 3. a) Cluster analysis for identifying groups among the farms according to energy intensity (EI), and water and carbon footprint (WF and CF, respectively), b) Dendrogram based on squared Euclidian distance: SP, R, OR, DR stand for spearmint, rosemary, oregano, and Damask rose respectively; O and C stand for Organic and Conventional, respectively (e.g. SPO stands for spearmint organic). Numbers indicate the 4 cluster groups for the 50 aromatic plant farms.

4. Discussion

4.1. Energy balance

Currently, the data in the literature about the energy balance of MAPs are scarce. The results of this research revealed significantly lower energy inputs in organic spearmint farms, compared to the conventional. The differences were attributed to the higher use of machinery, fertilizers and fuel (Table 2; Appendix A) in the conventional farms. However, because of the higher yield in conventional farms (Table 1), the outputs were higher than in the organic. For this crop, the efficiency (outputs divided by inputs) was higher in the organic farms than in the conventional, and the EI (MJ/kg) was significantly lower in the organic than in the conventional farms.

Similar results to spearmint, regarding the energy inputs, were observed for Damask rose where the organic farms had lower inputs than the conventional. However, the energy outputs for the two systems were similar (Table 2). Even though the yield of conventional farms was higher than that of organic farms (Table 1), the pruning residues (that were also included in the energy balance calculations) were higher in the organic farms, yielding similar results for the total energy outputs. The efficiency of the organic farms was higher while naturally the opposite was observed for EI (Table 2). In Damask rose, higher use of machinery, fuel and irrigation in the conventional farms (Table 2; Appendix B) resulted in the observed differences between the two management systems.

The results for the energy analysis in oregano showed that organic farms have lower inputs and outputs compared to the conventional (Table 2). The differences are attributed to the higher energy inputs for machinery use, fertilization, irrigation and fuels (Table 2; Appendix C). The difference in the energy outputs resulted from the higher yield in the conventional farms (Table 1). The efficiency of the organic farms was higher that of conventional farms, while the opposite was observed for EI, but the difference was not significant.

Finally, for rosemary energy inputs and outputs were lower in the organic farms while the efficiency and EI were not statistically different between the two systems (Table 2). The difference in the inputs is attributed to the use of fertilizers and pesticides in the conventional farms (Appendix D; Table 2) and the outputs were higher in the conventional due to higher yield (Table 1).

The EI (MJ/kg) index is useful to decision makers to identify crops and farming systems to regulate the balance between environmental sustainability and agriculture. The obtained values for the four MAP species ranged from 0.18 to 5.80 MJ/kg (Table 2). The lower value was observed for organic spearmint and the higher for conventional Damask rose (Table 2). In a recent study, Michos et al. (2018) reported EI values for grapevine, kiwi and apple farms ranging from 0.99 to 15.52 MJ/kg. On farms located in Natura 2000 sites, low inputs resulted in low EI (Litskas et al., 2011). Low EI values were also reported for low input apple orchards in Greece

(Kehagias et al., 2015). The farms in the current study achieved similar EI values with Xynisteri vineyards cultivated in several areas in Cyprus (Litskas et al., 2013). For Xynisteri, a local variety, the range for EI was 2.5–4.2 MJ/kg. Similar values for EI were obtained for organic and conventional vineyards cultivated in Northern Greece (Kavargiris et al., 2009). However, higher values (27.85 MJ/kg) were reported for intensively managed sweet cherry orchards (Litskas et al., 2011). The EI value for intensively managed, conventional, olive groves in Greece was even higher, reaching 59 MJ/kg (Genitsariotis et al., 2000) while the value for organic farms was much lower at 17.5 MJ/kg (Kaltsas et al., 2007). In all studies the increased EI is linked to increased inputs, such as fuel, fertilizers, pesticides and irrigation water. Yield is also important as EI is minimized when inputs are reduced and outputs are maximized (Michos et al., 2018). Local varieties, well adapted to the soil and climatic conditions, have the potential to be managed in such a way that decreases the EI. Our results indicate that intensity in organic farms is lower than that in conventional, but differences were significant for spearmint and damask rose only (Table 2).

Efficiency of farming systems (energy outputs divided by inputs; dimensionless) is another useful indicator for sustainability in agriculture (Alonso and Guzmán, 2010; Kehagias et al., 2015; Michos et al., 2018). An energy analysis can indicate ways to decrease energy inputs and increase energy efficiency. In our research, the lowest efficiency value (Table 2) was achieved for conventional rose farms (0.69) and the highest for organic oregano (11.02). Efficiency was consistently higher in organic than in conventional farms (Table 2), a finding which is in contrast to the results of Alonso and Guzmán (2010) who compared the efficiency of organic and conventional farms in Spain. They estimated average energy efficiency values of 0.45 for organic and 1.22 for conventional farms. Efficiently values for different crops were as follows: arable crops, 1.05 and 4.45 (organic and conventional, respectively), vegetables, 0.13 and 0.20, irrigated fruits, 0.86 and 3.3, and rainfed orchards, 0.78 and 1.3. Michos et al. (2018), in their research on kiwi, grapes and apple farms determined lower efficiency values (0.16–1.13). In other studies, the indicator ranged from 0.11 to 3.5 for grapes (Kavargiris et al., 2009; Litskas et al., 2013), 0.7–0.9 for apple orchards (Kehagias et al., 2015), 0.48–0.82 for cherry farms (Litskas et al., 2011) and 3.31 for olive groves (Kaltsas et al., 2007). The efficiency of MAPs farms (Table 2) is much higher than that of other crops and they could be a very good option in environmentally sensitive areas, such as Natura 2000 sites in Mediterranean countries, where these plants can be easily cultivated (Tzortzakis et al., 2011; Chrysargyris et al., 2017a, 2017b).

4.2. Carbon footprint

The GHG emissions for spearmint were significantly lower in the organic farms in comparison to the conventional (Tables 3 and 4). The CF in the conventional farms was two times higher than that of organic farms (Table 3) when the emissions were expressed per kg and three times higher when the emissions were calculated per ha (Table 4). This difference between the two systems is attributed to the use of synthetic fertilizers and pesticides in the conventional farms. The use of manure as fertilizer in the organic farms reduced the total emissions due to carbon storage in the soil (Tables 3 and 4; Appendix A). The use of synthetic fertilizers leads to increased soil N_2O emissions in the conventional farms, which is more evident if the data are expressed as kg CO_2-eq/ha (Table 4).

The CF for organic Damask rose was three times lower than that of conventional (Table 3). The difference is attributed to the use of synthetic fertilizers which also correspond to higher N_2O emissions from the soils and higher use of field energy in the conventional farms. Damask rose farmers did not add organic fertilizers in either management system, yielding zero carbon storage in the soil. When the emissions are expressed per ha (Table 4), the emissions in the conventional farms were almost four times higher than those in the organic farms.

No significant differences in CF were observed for oregano between the two management systems (Table 3). The slightly higher CF or conventional oregano resulted from the use of synthetic fertilizers and pesticides. Moreover, carbon storage due to the use of manure (Table 3; Appendix C) decreased the CF for organic oregano. Emissions per ha of land were twice as high in conventional farms compared to the organic (Table 4).

Finally, a similar situation to oregano was observed for rosemary, with no significant differences between the two systems in the CF (Table 3). N_2O soil emissions were higher in the organic farms, due to the increased use of manure (Table 3; Appendix D). When the GHG emissions were expressed per ha of cultivated land, the values for conventional oregano were two times higher than that for organic (Table 4).

In the current study, the CF for MAPs ranged from 0.05 to 0.463 kg CO_2-eq/kg. The lower values were for organic rosemary and the highest for conventional Damask rose farms (Table 3). Currently there are no data for GHG emissions from the management of MAPs farms. Clune et al. (2017) in their systematic review of GHG emissions for different fresh food categories (plant or meat) produced all over the world under different management systems, provided a range of mean values from 0.04 to 79.14 kg CO_2-eq/kg of product. The lower value was for carrots and the higher for buffalo meat. In the same research, the highest value observed for plant species was for lettuce produced in a heated greenhouse, with a CF value of 4.51 kg CO_2-eq/kg. Mean CF values for other important cultivated plant species were as follows: oats 0.44, maize 0.63, wheat 0.51, and rice 2.66, vegetables 0.47, fruits 0.50, and tree nuts 1.42 kg CO_2-eq/kg. The highest CF values for fruits were recorded for tangerines while in the case of nuts, pistachios had the highest CF. Finally, the CF values for fish and meat products were much higher than that for plant species. The lower average CF value for this category of food was for fish (4.41) and the higher for beef (28.73). The range of the CF for beef meet was 10.74–109.5, depending on the management practices (Clune et al., 2017).

4.3. Water footprint

There were no significant differences between the total WF (L/kg) for conventional and organic farms for spearmint (Fig. 2a). In general, more water (irrigation + rain) was applied per season in conventional farms while the yield was lower in the organic (Table 1). This led to lower WF (total, blue and green) in the conventional farms in comparison to the organic. When the WF is expressed as m^3/ha (Fig. 2b), conventional spearmint farms have significantly higher water consumption than organic.

The total WF (L/kg) for Damask rose was significantly higher in organic than in conventional farms (Fig. 2a). Although all the farms are in the same area and rainfall was 410 mm, the lower yield in the organic farms resulted to differences between the two systems for green WF. Irrigation amount (m^3/ha) was significantly higher in the conventional (Fig. 2b; Appendix B), but when expressed in water volume per kg of product (blue WF) there was similarity between organic and conventional farms (Fig. 2).

The comparisons of the total WF (L/kg) for oregano and rosemary showed that there were no significant differences between conventional and organic farms (Fig. 2a). For oregano, irrigation water (m^3/ha) was significantly higher in the conventional farms (Fig. 2b; Appendix C) and the yield was also higher, compared to the organic (Table 1). Similar results were obtained for rosemary farms where irrigation was also higher (but no significant difference was found) in the conventional farms (Fig. 2b; Appendix D) but the differences in yield (Table 1) led to non-significant differences for the total WF between the two systems.

The WF in the studied farms ranged from 13 to 277 L/kg (or m^3/ton f.w.), with the lower values obtained for the conventional spearmint and the higher for the organic Damask rose. While data exist for the WF of various cultivated plants, little is known for that of MAPs. In addition, the typical expression of the WF is in L/kg and values per ha are usually not presented. In their review paper, Mekonnen and Hoekstra (2011) presented average global (total) WF values for sugar crops (197 L/kg), vegetables (322 L/kg), fruits (962 L/kg), cereals (1644 L/kg), pulses (4055 L/kg) and nuts (9063 L/kg). Obviously, MAPs have a quite low WF and could be planted in semi-arid and arid areas, such as the Mediterranean. The WF for animal products is much higher than that of animal products (Mekonnen and Hoekstra, 2011). For example, sheep/goat and bovine meat have a WF at 8,763 and 15,415 L/kg of meat, respectively. Mekonnen and Hoekstra (2011) also included grey water in their calculations, which is the amount of fresh water required to assimilate pollutants to meet specific water quality standards. In their data, grey water is up to 15% of the total WF. According to them, the global hotspots for high total WF are the Mediterranean, where the research took place, Central Europe, North America, Indonesia, Argentina, India, China and coastal areas of South Australia.

4.4. Cluster analysis

The variables EI, CF and WF were used in the cluster analysis to identify groups of similar farms (Fig. 3). Accordingly, four clusters were observed with the first one containing most of the farms and having the lower values of EI, WF and CF. In this cluster, organic and conventional spearmint, rosemary and oregano farms were grouped (Fig. 3). The second cluster contained the organic Damask rose farms ($n = 8$), having higher values for all three parameters than the first cluster (section 3.4; Fig. 3). The third and the fourth clusters contained the conventional Damask rose farms, where the highest values for EI, WF and CF were observed. The analysis shows that MAPs, such as spearmint, oregano and rosemary that require low inputs and have adequate yield could lead to low environmental impact agricultural systems. Where inputs are increased to obtain higher yield and income, for instance in conventional Damask rose farms, higher environmental impact is expected, questioning the long-term sustainability of the farms and methods. Similar analysis has been applied for other crops such as kiwi, apple and grape farms (Michos et al., 2018) and indigenous Mediterranean grapes (Litskas et al., 2013). The results of these two studies support our findings, in that environmental advantages in agricultural management come from reduced inputs.

5. Conclusions and policy implications

In this research LCA was applied to determine the EI, CF and WF in organic and conventional farms, where spearmint, oregano, rosemary and Damask rose were cultivated. The EI and CF per functional unit of product were significantly lower in organic spearmint and Damask rose farms, compared to conventional. However, low input, conventional cultivation of oregano and rosemary yielded EI and CF values similar to those for organic production.

The WF per functional unit of product was generally higher in organic farms for all species, but significant differences were observed only for Damask rose. The results suggest that at least for Damask rose, water use per functional unit of the product is higher for organic than conventional Damask rose farms.

Enhancing the efficiency of the water-food-energy nexus is a major policy instrument to achieve sustainability in agriculture. The results of the current work show no clear divide between organic and conventional production for EI, CF and WF per functional unit of product, but rather a species dependent result. Conventional Damask rose farms might be more suitable for areas with low water availability, as they use less water (lower WF) per functional unit of product. However, if EI or CF are the metrics of choice, then organic Damask rose farms are more efficient than conventional ones. The low CF and WF values identified in the current work, point to the potential for zero CF and very low WF cultivation of certain MAP species, if management practices, such as deficit irrigation and carbon storage in the soil are applied are fine-tuned.

MAP farms can be managed in ways that reduce resource consumption (e.g. water, energy, materials), and are especially suited for areas with poor soil fertility, as they are not considered nutrient demanding crops. In the Mediterranean region, where they are typically present in poor soils, they could contribute to agricultural sustainability by preventing further deterioration of soil resources. Future work needs to include additional MAP species cultivated in the open or in greenhouses, as currently there is a lack of relevant data. Such analyses can lead to the selection of the most efficient species that meet consumer demands while reducing the footprint of the agricultural sector.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2019.06.065.

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