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Placing Ecosystem Services within the Water–Food–Energy–Climate Nexus: A Case Study in Mediterranean Mixed Orchards

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Abstract: We used Cyprus as a model to link the Water–Energy–Food–Climate (WEFC) nexus indicators (e.g., carbon and water footprints) to the ecosystem services (ES) provided by 39 mixed orchards (stone fruits and nuts) on organic (Org) and conventional (Conv) farms. Food provision was lower for Org than Conv orchards. Management practices in Org mixed orchards better support climate change mitigation and water flow regulation. Soil quality parameters (e.g., organic matter and soil respiration), Arbuscular Mycorrhizal Fungi (AMF), and farm attributes (e.g., tree age) were significantly correlated to the GHG emissions per Mcal of food. Using cluster analysis, orchards were grouped based on WEFC indicators. Finally, a simple approach was developed to allow a rapid link between the WEFC and ES and to support decision making related to land use. This approach highlighted that in the case of Mediterranean mixed orchards, the main objective towards sustainability should be the balance between input management, food production, and ES from agroecosystems, rather than solely the attainment of high yields.

Keywords: CICES; climate change; nexus; organic farming; permanent crops; sustainability indicators; sustainable agriculture

Citation: Ioannidou, S.; Litskas, V.; Stavrinides, M.; Vogiatzakis, I.N. Placing Ecosystem Services within the Water–Food–Energy–Climate Nexus: A Case Study in Mediterranean Mixed Orchards. *Agronomy* **2022**, *12*, 2224. https://doi.org/10.3390/agronomy12092224

Academic Editor: José Casanova Gascón

Received: 18 July 2022
Accepted: 15 September 2022
Published: 18 September 2022

1. Introduction

The past 20 years have seen the parallel development of various frameworks that investigate the use of resources and human well-being. One of these frameworks is the ecosystem services (ES) assessment, which started with the Millennium Ecosystems Assessment (MEA) and TEEB [1] and culminated in CICES 2018 [2,3]. ES-based assessments attempt to link goods and services derived from ecosystems to human well-being and have been applied by now in a variety of geographical contexts [4–6], scales [7–9], and ecosystems, including agroecosystems [10–13]. The ecosystem services assessment is important to understand the link between ecosystems and their benefits and this supports informed decision making [14].

In addition to the ES assessment, the concept of the Water–Energy–Food–Climate (WEFC) nexus is rapidly expanding in research and policy agendas as a novel way to address complex resource and development challenges [15]. This approach highlights the interlinkage among the water, energy, and food production sectors [16], while the influence of climate change is also incorporated in selecting policies and strategies for sustainable resource management [17,18]. In striving to secure food provision to a continuously increasing human population, agriculture has become the most important water resource user on the global scale [19]. Consequently, this has resulted in pollution and competition among production sectors [20]. In 2019, the annual (global) emissions from energy use in agriculture were about 523 million tons (Mt CO_2-eq yr^{-1}) while, if electricity is included, this reaches 1029 Mt CO_2-eq yr^{-1}, a 7 % increase since 1990 [21]. The Water–Energy–Food–Climate (WEFC) nexus could be studied in agroecosystems by quantifying key indicators, such as the carbon footprint (CF; kg CO_2-eq per ha or kg), energy intensity (EI; MJ per ha or kg), water footprint (WF; m^3 per ha or kg), and yield (kg per ha or Calories per ha) [22].

Linking the WEFC nexus to ES provided by food production systems after selecting appropriate indicators may enhance sustainable food production and climate change mitigation. Indicators could give a summary of significant and quite complex systems such as the WEFC, quantify trends, and communicate to stakeholders what the WEFC and ES represent [23,24]. The carbon footprint is an indicator that is directly linked to climate regulation and global warming potential of products and organizations [25]. Crop yield is the most representative indicator related to food provision [10,13]. Water footprint is linked to water provision and sustainable water management [26–28] while energy intensity could be also linked to food production systems and food provision [22,29].

There are few studies attempting to link WEFC and ES, most of them looking into the introduction of PES (payment for ecosystem services) schemes. One such example focused on water quality issues to illustrate the role of the WEFC nexus perspective in promoting ES in agriculture [30]. The research focused on pesticide reduction and irrigation water allocation for renewable energy production in Asian and African countries. A similar approach is presented in the case of a hydropower project in Colombia [31]. Incentives were provided to the farmers to reduce irrigation water consumption, to increase energy production and safeguard food provision.

Moreover, a nexus approach is valuable to identify synergies and trade-offs between sectors and to foster the sustainable and efficient use of resources, particularly in light of climate change [18]. An anthropogenic pressure on an ecosystem function or service can have indirect effects on many other functions and services through different connections. An example is the overuse of fertilizers which causes alterations in the biogeochemical cycles. Excess nutrients enhance primary production in water bodies, leading to eutrophication and thus impeding the maintenance of water quality (regulating service) [18]. Nevertheless, there are currently few studies that are using indicators to link WEFC and ES, especially in orchard systems. These are typically high-input systems that maximize yield and profit, which are globally present and very important for food and income security in the agricultural sector [32,33].

Orchards in insular environments are mostly located in mountainous and semi-mountainous areas and are associated with a wide range of ecosystem services (ES) [34,35]. They support several services, such as climate regulation, pollination, and pest and weed control, potentially to a higher degree than annual crops or monocultures [13,36–39]. In addition, they provide water retention and purification, nutrient cycling services [40], and soil aggregation [13,41]. Mixed orchards could have additional positive impacts that are linked to climate change mitigation and to the maintenance of C stocks [10,42].

Research on ES from orchards remains limited [34] and it is usually confined to monoculture systems [43,44], which are quite different from mixed orchards in characteristics (size and planting density) and management practices. Additionally, although model estimations remain, the principal approach [44] of using actual measurements of soil properties are very important for ES assessment [45]. Other neglected aspects in mixed orchards are the effects of the management system (e.g., Org vs. Conv) and farm attributes (e.g., tree age) on WEFC parameters and ES provision.

The aim of this research was to link WEFC parameters, as expressed with the use of widely employed indicators (e.g., CF, WF, EI, and yield), with ES in nut and stone fruit mixed orchards, with a view to support land use design for optimizing ES and minimizing agriculture's environmental impact, as exemplified in Cyprus. The objectives were to:

- Estimate CF, WF, EI, and yield from Org and Conv mixed stone fruit and mixed nut orchards.

- Build a framework for linking WEFC and ES, based on the CICES framework.
- Assess the potential of mixed orchards to contribute to low environmental impact agriculture schemes and support ES provision in islands.

2. Materials and Methods

2.1. Study Area, Orchard Selection, and Related Data

The cultivated area in Cyprus [46] is 114,193 ha, of which 80,765 ha are field crops (e.g., cereal, fodder, industrial, and legumes), 7138 are vegetables and melons, and 26,290 ha are fruit and other tree crops (the majority of which are olives and grapes). Fruit and nut orchards on the island are cultivated mainly in mountainous and semi-mountainous areas where the climate is most suitable. They represent an important sector for the rural economy of the island since they provide a source of income for producers while contributing to the retention of the population in the country. Organic (Org) orchards in Cyprus cover an area of 439 ha [47]. Pomes (e.g., apples and pears) cover 74 ha, stone fruits (e.g., plums and apricots) account for 136 ha, and 229 ha are planted with nut crops. The yield in organic orchards in Cyprus ranges from 1 (nuts) to 11.85 (apples) tons ha^{-1} year^{-1} (average 2013–2019; [47]). Conventional (Conv) orchards cover an area of 4407 ha (2018 data) of which 2552 ha are almonds, 371 ha are apples, 369 ha are plums, and 291 ha are peaches. The yield in conventional orchards varies from 0.14 ton ha^{-1} for almonds to 26.23 tons ha^{-1} for figs (average data 2013–2018; [46]). The annual production of fruits and other tree crops (Conv and Org) is 140,863 tons, which are usually consumed in the local market.

Thirty-nine mixed orchards were selected for this study (Figure 1; Table S1) and classified into two groups. The first group comprised 21 farms, (7 conventional and 14 organic), where the dominant cultivated tree was a stone fruit (e.g., cherry, peach, and plum). The second group comprised 18 orchards (12 conventional and 6 organic), where the main tree was a nut (e.g., almonds, walnuts, and pistachios).

Figure 1. Farm locations in Cyprus. Organic farms are shown in pink and conventional in green.

The recorded data included: (1) farm location (coordinates; see Figure 1), (2) farm size (ha), (3) tree age (years), and (4) yield (kg ha^{-1}). Most of the orchards are considered typical for the tree cultivation scheme in Cyprus, where more than one crop species is present in the same plot of land, typically less than 1 ha in size. Soils on the farms are generally poor in organic matter and closely associated with parent material and landscape position [48]. Thin (leptic) and stony (lithic) soils dominate the mountainous areas where many of the orchards are located [48].

The farmers managing the orchards belong to the collaboration network of the Agricultural Research Institute (ARI) and they participate in state projects for recording data for agricultural statistics. They were all volunteers in this study and agreed to provide data on management practices and soil samples for analysis. The selection criteria were that (1) the farmers have mixed orchards and (2) organic farmers are certified and included in the National Registry of Organic Farming kept by the Department of Agriculture in Cyprus. The areas selected are the most important regarding the presence of orchards in Cyprus. In addition, all main soil types were covered (Figure 1).

2.2. Soil Parameters

Soil samples (one composite sample per orchard; 0–40 cm depth) were obtained from the orchards to determine (1) organic matter, (2) organic nitrogen, (3), number of weed species, (4) soil respiration, and (5) soil aggregate stability. Root samples were also collected to determine (6) Arbuscular Mycorrhiza Fungi (AMF) presence. The data refer to the period from 2012–2014. These parameters were selected as they are closely related to the capacity of soils to provide ES [49–51].

For the determination of soil organic matter and nitrogen, one composite soil sample (collected from various locations within the same orchard) was collected per farm (0–40 cm depth). For the determination of organic matter, the Walkley–Black method was followed [52]. Organic nitrogen in the soil was determined following Kjeldahl digestion [53].

In each orchard, a 100 g (composite) root sample was collected from the cultivated trees (various species) from a 40 cm depth to quantify AMF presence (% of root colonization), following the methodology presented by the authors of [54]. Microbial activity in the soil was estimated after quantifying the soil respiration rate [55,56]. Briefly, the soil was sampled, dried (2–3 days, lab temperature), sieved (2 mm), and the water content was adjusted to 50% WHC. It was then incubated at 25 °C for 24 h with NaOH vials (CO_2 traps). After incubation, the NaOH vials were removed and titrated with 0.02 N HCl to determine the amount of CO_2 evolved from the soil sample during incubation. It was expressed as mg CO_2 per 100 g of soil.

Mean weight diameter (MWD; measured in mm) as a proxy for soil aggregate stability was quantified, as described by the authors of [57]. The basic idea is that larger aggregates imply greater stability with MWD being the most widely used index for this purpose [58]. In practice, a calculation based on the summation of size classes is determined from sieving (using different mesh diameters; range 2–20 mm). The MWD comes directly out of a lognormal fitting process, interpretable as the diameter at which one-half of the soil mass consists of smaller aggregates and one-half of larger aggregates [57].

The number of weed species was determined following the seedling emergence method, as presented in [59]. Each (composite) soil sample (0–40 cm depth) from the farms was placed over coarse sand, which was previously sterilized. Samples were then sub-irrigated to maintain soil moisture and assist seed germination. The weed seedlings that emerged were identified and counted and then removed. The number of species present in each sample was recorded.

More details for soil parameter determination can be obtained in Ioannidou et al. [13]. The results of soil parameter determination are provided in Table S2 (Supplementary Material).

2.3. WEFC Indicators

2.3.1. Yield

For each farm (stone fruits and nuts), yield (kg ha^{-1}) was recorded as the average of the years 2012–2014. In addition, the weight (kg) of the fruits and nuts was converted to kcal, based on the calorimetric content (Table 1). Most of the farms had a main tree species (e.g., almonds) and individual trees of other species (e.g., walnuts and pistachios). In such cases, the yield was that of the main species (converted to Kcal) plus minor tree species (also in Kcal).

Table 1. Calorimetric content for the fruits and nuts (raw) used in this study. Obtained from https://caloriecontrol.org/, (accessed on 6 April 2022) and https://www.nutritionvalue.org/ (accessed on 6 April 2022).

Tree Species	Kcal kg^{-1}	Tree Species	Kcal kg^{-1}
Almonds	5.79	Cherries	0.634
Pistachios	5.69	Nectarines	0.442
Walnuts	6.54	Plums	0.454
Apricots	0.486	Peaches	0.394

2.3.2. GHG Emissions

Greenhouse gas emissions were quantified based on (1) measured diesel fuel consumption (transportation and field use for soil cultivation) and (2) indirect soil emissions due to fertilizer use. Diesel fuel consumption (L/ha) was converted to GHG emissions by using the emission factor 3.8 kg CO_2-eq L^{-1}, obtained after employing the OpenLCA software for modeling fuel use in agricultural machinery (Table S3). This value includes production, transportation, and use of the fuel. Application of nitrogen with organic and synthetic fertilizers was recorded and converted to CO_2-eq after using the LCA processes for producing and using organic and synthetic fertilizers (Table S3). Due to the application of nitrogen fertilizers in the soil (organic and conventional), dinitrogen monoxide (N_2O) emissions were calculated using the emission factor 0.0057 kg N_2O per kg N [60] and by multiplying by 298 (global warming potential) to convert N_2O to CO_2. The GHG emissions (CF) were expressed as kg CO_2-eq ha^{-1}.

The production of machinery (e.g., emissions due to tractor manufacturing) was not considered in the emission calculations. Additionally, electricity use (mainly for irrigation; public irrigation network) was not considered since data were not available.

2.3.3. Water Footprint and Energy Intensity

Irrigation water was monitored on the selected farms as m^3 ha^{-1} based on the irrigation schedule to quantify the water footprint (WF). Rainwater was not included in the calculations.

Diesel fuel (field) consumption (L ha^{-1}) was converted to energy (MJ ha^{-1}) by using the energy content 38 MJ L^{-1} to calculate the energy intensity (EI) for the selected farms.

2.4. Statistical Analysis

For the data obtained after CF, EI, WF, and yield calculations, summary statistics were calculated. Kruskal–Wallis tests, using the Bonferroni correction (95% intervals), were performed for testing whether there is a significant difference in the median values of EI, CF, WF, and yield between organic and conventional mixed orchards.

Multiple linear regression was used to explore the relationship between GHG emissions and soil parameters (physical, chemical, and biological; see Section 2.2). For this purpose, the GHG emissions were expressed as kg CO_2-eq per MCal of food produced from (a) nuts and (b) stone fruit mixed orchards. For the fitting procedure, backward stepwise selection was applied with p value (>0.05) as the selection criterion to remove the independent variables and simplify the model. The Durbin–Watson (DW) statistic was used to test the significant correlation of the residuals.

Cluster analysis, using Ward's Method, was used [61] to identify groups of mixed orchards, showing similarity among the following WEFC parameters: (1) water (m^3 ha^{-1}), (2) energy intensity (MJ ha^{-1}), (3) yield (MCal ha^{-1}), and (4) GHG emissions (kg CO_2-eq ha^{-1}). Ward's minimum variance criterion was used for cluster formation and dissimilarity between the studied orchards was measured with the squared Euclidean distance [62]. The analysis was performed in STATGRAPHICS CENTURION v.19 (STATPOINT INC).

2.5. Linking WEFC Parameters and Ecosystem Services

Table 2 presents the linking of WEFC parameters to ecosystem services, based on the CICES V5.1 framework (see spreadsheet https://cices.eu/resources/, (accessed on 3 March 2022)) [3].

Table 2. Linking WEFC parameters to ecosystem services.

WEFC Parameter	Ecosystem Service	CICES v5.1	Comment	Scoring System
GHG emissions (Carbon Footprint)	Atmospheric composition regulation	2.2.6.1	GHG emissions due to fuel and energy use in the field as well as emissions from the production of fertilizers and relevant soil emissions lead to impacts in atmospheric composition and affect climate regulation.	Red (=0 points); higher values class Orange (=1 point); medium values class Green (=3 points); lower values class
Water footprint (Irrigation water)	Water (surface and groundwater) used for nutrition, materials; regulation of flows	4.2.1.1 and 4.2.2.2; 2.2.1.3	Water use for irrigation increases yield and food provision but affects water cycle and water availability for ground and surface water bodies and related ecosystems.	
Energy Intensity	Food provision	1.1.1.1; 2.2.6.1	Energy inputs is typical for the agricultural production and food safety, and it is linked to food provision. Energy production is related to GHG emissions and energy use for food production is related to climate change.	
Yield	Food provision	1.1.1.1	The yield of the orchards and the calories from the fruits and nuts is linked to food provision.	Red (=0 points); lower values class Orange (=1 point); medium values class Green (=3 points); higher values class
Combined score				Lower score = worst case for ES = 0 (all WEFC parameters are red; 4 × 0) Higher score = best for ES = 12 (all WEFC parameters are green; 4 × 3) Overall classification 0–4: Red; 5–8 Orange; 9–12 Green

We developed a simple scoring system to link the WEFC nexus parameters with ecosystem services after these steps:

Step 1: For each of the four WEFC nexus parameters evaluated, we created three classes (high, intermediate, and low; see Figures S1 and S2 Supplementary Material). In the case of GHG emissions (CF), water footprint (WF), and energy intensity (EI), the higher the value, the higher the negative impact to the respective ES (Table 2).

Step 2: The class with the higher values for CF, WF, and EI receives zero (0) points, the intermediate receives one (1), and the lower receives three (3) points, as lower GHG emissions, energy intensity, and water footprint are beneficial for ES. The opposite was followed for the case of yield as higher yields lead to higher values for the ES food provision (Table 2; Figures S1 and S2 Supplementary Material).

Step 3: Based on the scoring system developed, the score (0, 1, or 3) for each of the WEFC parameters was summed to obtain a total score (Table 2). Therefore, the linking scale for WEFC parameters and ES ranged from 0–12 (Table 2).

Step 4: The 39 farms were classified based on the WEFC parameters (Table S4; Supplementary Material) and the link to ES was made.

3. Results

3.1. WEFC in Mixed Orchards

3.1.1. Nuts

The WEFC parameters for the case of organic (Org) and conventional (Conv) mixed orchards are shown in Figure 2. Median yield (lower–upper quartile) was 18.23 (6.08–22.1) and 22.71 (22.71–26.0) Mcal ha^{-1} for Org and Conv orchards, respectively. The comparison of the median values showed that conventional mixed orchards had a significantly higher yield than organic (Figure 2A). The median values (lower–upper quartile) for the GHG emissions (CF) were 928.3 (928.3–3163.5) and 2431.2 (803.4–6698.7) kg CO_2-eq ha^{-1} for organic and conventional farms, respectively. The median values (lower–upper quartile) for water consumption was 658.0 (658.0–1418.0) and 1399.0 (113.0–3923.0) m^3 ha^{-1} in Org and Conv orchards, respectively. Energy intensity was 3707.7 (3707.7–12,725.6) and 9972.8 (3471.8–28,021.8) MJ ha^{-1} in organic and conventional mixed nut orchards, respectively. There was no statistically significant difference for CF, WF, and EI between Org and Conv mixed orchards (Figure 2B–D).

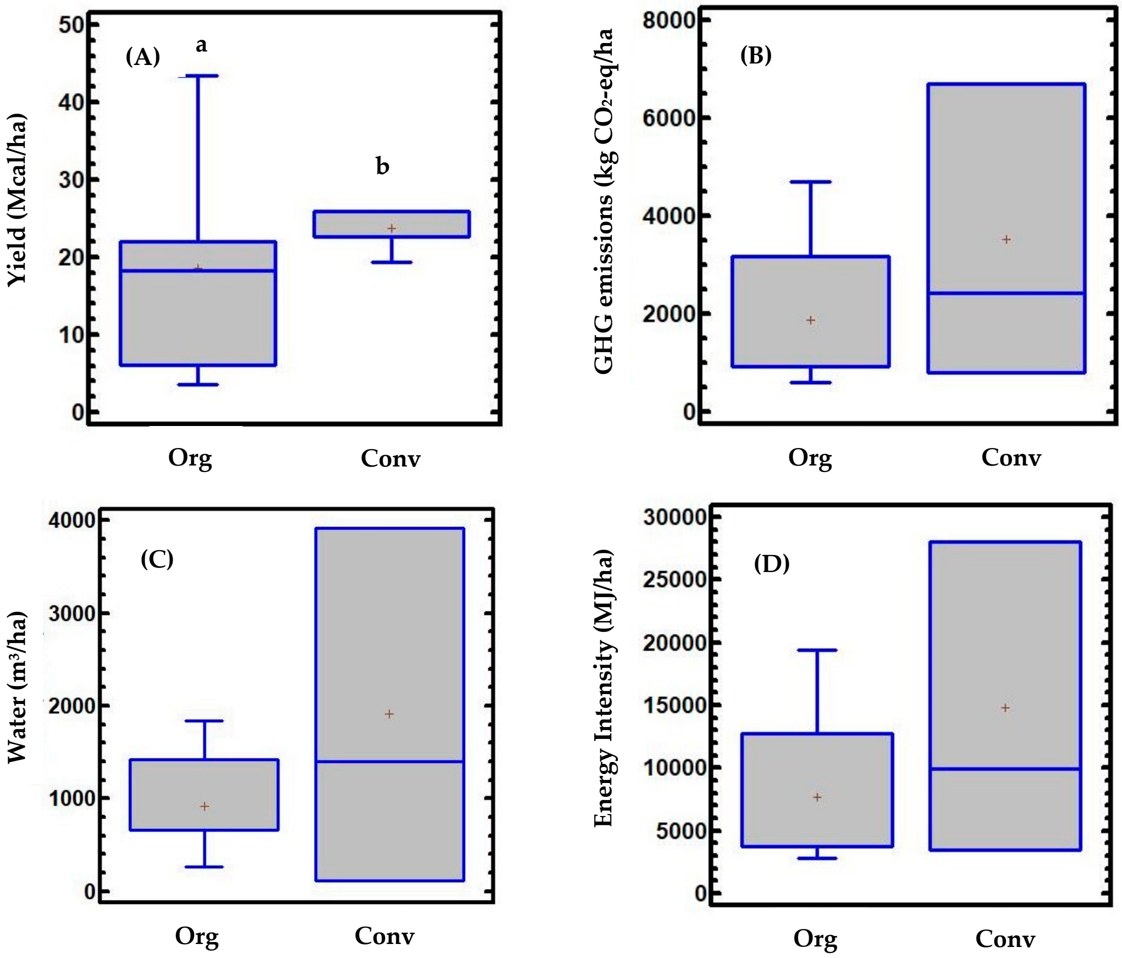

Figure 2. (**A**) Yield (Mcal ha^{-1}), (**B**) carbon footprint—CF (kg CO_2-eq ha^{-1}), (**C**) water footprint—WF (m^3 ha^{-1}), and (**D**) energy intensity—EI (MJ ha^{-1}), for organic (Org) and conventional (Conv) mixed (nuts) orchards. Different letters above the boxplots indicate statistical difference ($p < 0.05$).

The median values (lower–upper quartile) for CF, WF, and EI per kg of product were 0.591 (0.293–1.064) kg CO_2-eq, 0.245 (0.208–0.572) m^3, and 2.616 (1.17–4.269) MJ, and 0.699 (0.203–1.674) kg CO_2-eq, 0.409 (0.029–0.981) m^3, and 2.862 (0.879–7.005) MJ in the case of Org and Conv orchards, respectively. The calories per kg, for the case of the yield, are presented above (Table 1). The median yield in kg ha^{-1} was 3170 and 3950 for Org and Conv orchards, respectively.

3.1.2. Stone Fruits

In Figure 3, the WEFC parameters are presented for organic (Org) and conventional (Conv) mixed stone fruit orchards. The median yield (lower–upper quartile) was 2.588 (1.589–2.724) and 8.626 (7.88–9.477) Mcal ha^{-1} for organic and conventional stone fruit orchards, respectively. The comparison of the median values showed that conventional stone fruit orchards had a significantly higher yield than organic (Figure 3A). The median values (lower-upper quartile) for the GHG emissions (CF) were 1918.3 (1705.9–2508.1) and 2139.1 (2105.7–3281.9) kg CO_2-eq ha^{-1} for Org and Conv farms, respectively. The median water consumption (lower–upper quartile) was 3015.0 (3015.0–3135.0) and 4178.0 (3500.0–4200.0) m^3 ha^{-1} in organic and conventional orchards, respectively. The median energy use (lower–upper quartile) was 17,461.5 (15,923.9–23,743.3) and 14,162.7 (13,155.9–22,762.5) MJ ha^{-1}, in organic and conventional mixed nut orchards, respectively. There was no statistically significant difference for GHG emissions, WF, and EI between organic (Org) and conventional (Conv) mixed orchards (Figure 3B–D).

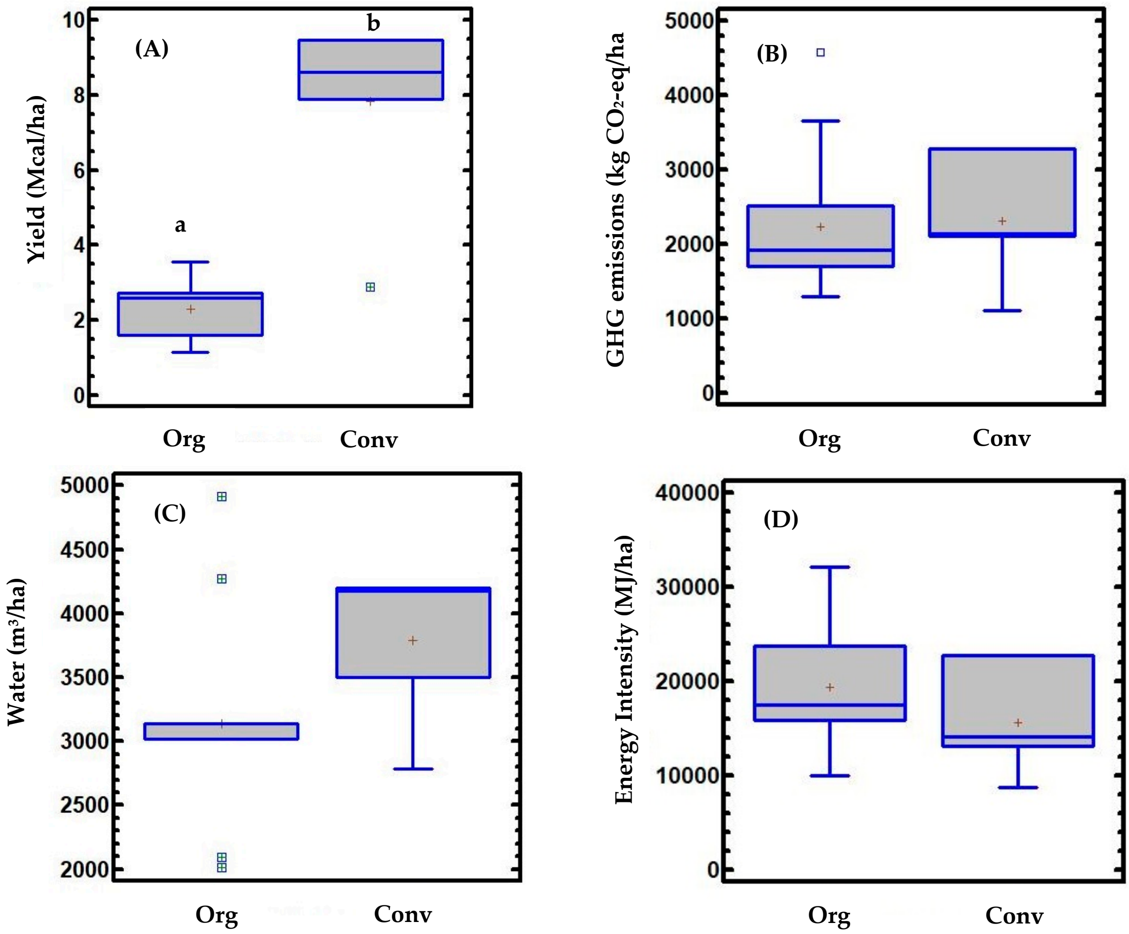

Figure 3. (**A**) Yield (Mcal ha^{-1}), (**B**) carbon footprint—CF (kg CO_2-eq ha^{-1}), (**C**) water footprint—WF (m^3 ha^{-1}), and (**D**) energy intensity—EI (MJ ha^{-1}), for organic (Org) and conventional (Conv) mixed (stone fruit) orchards. Different letters above the boxplots indicate statistical difference ($p < 0.05$). The squares above and below the boxplots symbolize outliers.

The median (lower–upper quartile) values for CF, WF, and EI expressed per kg of product were 0.404 (0.320–0.577) kg CO_2-eq, 0.623 (0.503–0.856) m^3, and 3.73 (2.910–5.467) MJ and 0.111 (0.110–0.164) kg CO_2-eq, 0.210 (0.179–0.210) m^3, and 0.726 (0.726–1.14) MJ in the case of organic and conventional orchards, respectively. The calories per kg, for the case of the yield, are presented above (Table 1). The median yield in kg ha^{-1} was 5023 and 19,500 for organic and conventional orchards, respectively.

3.2. GHG Emissions Relationship to Orchards Parameters

In the case of mixed nut orchards, GHG emissions per MCal of food, due to diesel and fertilizer production and use were not significantly related (*df* 17; *F*-ratio 0.66; *p*-value 0.704) to soil parameters (organic matter, soil respiration, organic nitrogen, and aggregate size), AMF, and farm attributes (trees age and weed species). On the other hand, there was a significant relationship between GHG emissions and soil parameters and between AMF and farm attributes for the mixed stone fruit orchards (*df* 20; *F*-ratio 13.94; $p = 0.0002$). The R^2 (adjusted for *df*) was 56.12 %. The backward selection process based on *p* value (>0.05) removed five variables (soil respiration, weed species, AMF%, organic matter%, and organic nitrogen%) to simplify the model. The Durbin–Watson (DW) statistic test showed that there was no indication of serial autocorrelation in the residuals at the 95.0% confidence level. In Figure S1, the observed vs. predicted values plot is presented. GHG emissions per Mcal of food was negatively correlated to tree age and positively to soil aggregate stability (MWD). The model equation was:

$$\text{Kg } CO_2\text{eq/Mcal} = -716.77 - 56.27 \times (\text{TA}) + 182.37 \times (\text{MWD})$$

where (TA) is the tree age (years) and (MWD) is the soil aggregate mean weight diameter (mm).

In Figure 4A, the model predictions (95% confidence intervals) are presented for GHG emissions (kg CO_2-eq $Mcal^{-1}$) for different tree age values while the other model parameters remained constant (as the average values observed for stone fruit orchards): soil respiration 31.1 (CO_2 mg per 100 g soil in 24 h and 25 °C), organic nitrogen 0.1 %, MWD 11.6 (mm), organic matter 1.1 %, number of weed species 5.9, and AMF 27.6%. In Figure 4B, the same procedure was followed for different values of MWD. In this case, the tree age was 10 years and the other parameters were set as previously presented.

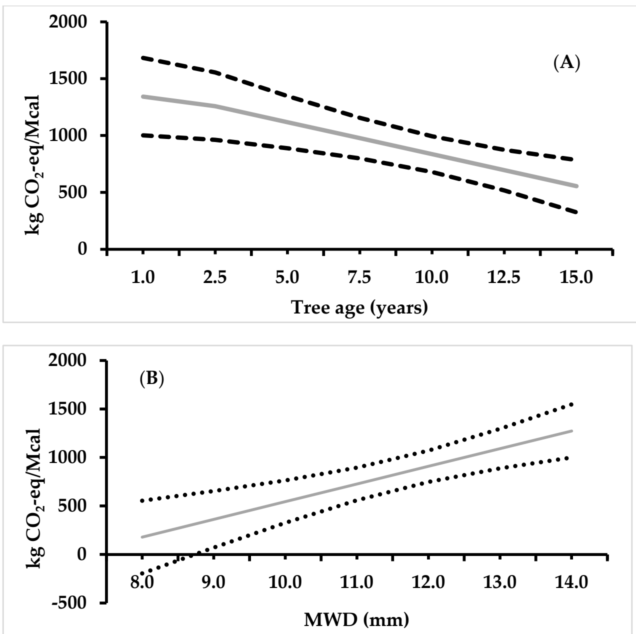

Figure 4. Model predictions (mean and 95% confidence intervals) for GHG emission values for different tree ages (**A**) and soil aggregate MWD (mm) (**B**).

3.3. Cluster Analysis

The orchards were grouped in three clusters for the case of mixed nut (Figure 5A) and mixed stone fruit orchards (Figure 5B), based on the WEFC parameters. The centroids are presented in Table 3.

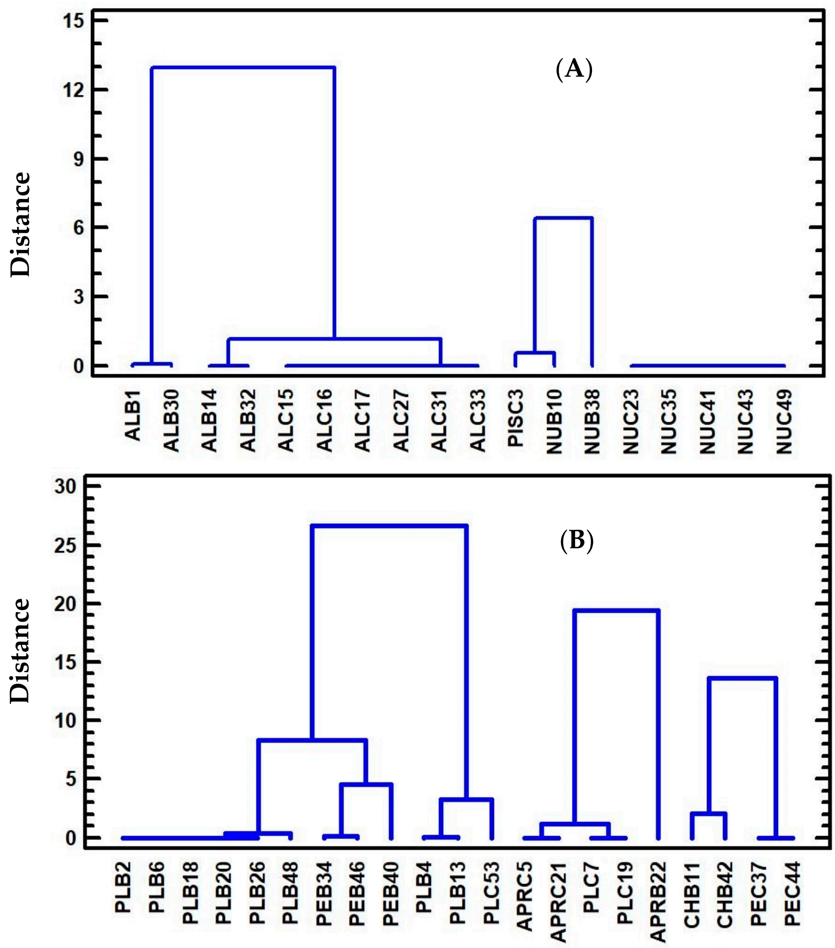

Figure 5. Dendrogram for the cluster analysis (Ward's method; squared Euclidean distance) in the case of the nuts (**A**) and stone fruit orchards (**B**). The code of each orchard is also provided after the main tree species present: AL: almonds; PIS: pistachios; NU: walnuts; PL: plums; PE: peaches; APR: apricots; CH: cherries.

Table 3. Centroid values of WEFC parameters for the three clusters in the case of nuts and stone fruit orchards.

Cluster	Members	Percent	EI MJ/ha	Yield (Mcal ha^{-1})	WF (m^3 ha^{-1})	CF (kg CO_2eq ha^{-1})
NUTS						
1	10	55.56	3477.3	18.245	291.3	819.76
2	3	16.67	16,198.2	28.3133	1980.67	3974.47
3	5	27.78	28,021.8	26.0	3923.0	6698.7
STONE						
1	12	57.14	17,444.1	2.101	2771.25	1891.35
2	5	23.81	12,936.7	7.732	4053.8	2011.1
3	4	19.05	26,413.4	5.287	4234.0	3696.57

3.4. Linking WEFC and ES

In Figures S2 and S3 (Supplementary Material), the classes obtained based on the values of the WEFC parameters for the mixed orchards are provided. Based on these classes and Table 2 (see Section 2.5), the 39 mixed orchards were grouped as presented in Table S4 (Supplementary Material) and the score (3 = high; 1 = intermediate; 0 = low), a proxy for ES delivery, was calculated for mixed nut (Table 4) and mixed stone fruit (Table 5) orchards. In Figure 6, the score for linking WEFC parameters to ES in the case of mixed orchards is provided.

Table 4. Classification of mixed nut orchards based on the ES score (3 = high (green); 1 = intermediate (orange); 0 = low (red)). MP: Management practices; B: organic; C: conventional; CF: carbon footprint; WF: water footprint; EI: energy intensity.

Code	MP	CF	WF	FOOD	EI	SCORE
ALB1	B	3	0	0	3	6
PISC3	C	1	1	1	1	4
NUB10	B	1	1	1	1	4
ALB14	B	3	3	1	3	10
ALC15	C	3	3	1	3	10
ALC16	C	3	3	1	3	10
ALC17	C	3	3	1	3	10
NUC23	C	0	0	1	0	1
ALC27	C	3	3	1	3	10
ALB30	B	3	3	0	3	9
ALC31	C	3	3	1	3	10
ALB32	B	3	3	1	3	10
ALC33	C	3	3	1	3	10
NUC35	C	0	0	1	0	1
NUB38	B	0	1	3	1	5
NUC41	C	0	0	1	0	1
NUC43	C	0	0	1	0	1
NUC49	C	0	0	1	0	1

Table 5. Classification of mixed stone fruit orchards based on the ES score (3 = high (green); 1 = intermediate (orange); 0 = low (red)). MP: Management practices; B: organic; C: conventional; CF: carbon footprint; WF: water footprint; EI: energy intensity.

Code	MP	CF	WF	FOOD	EI	SCORE
PLB2	B	3	1	0	1	5
PLB4	B	1	3	0	3	7
APRC5	C	3	1	3	3	10
PLB6	B	3	1	0	1	5
PLC7	C	3	0	3	3	9
CHB11	B	0	0	0	0	0
PLB13	B	1	3	0	3	7
PLB18	B	3	1	0	1	5
PLC19	C	3	0	3	3	9
PLB20	B	3	1	0	1	5
APRC21	C	3	1	3	3	10
APRB22	B	3	0	0	3	6
PLB26	B	3	1	0	1	5

Table 5. *Cont.*

Code	MP	CF	WF	FOOD	EI	SCORE
PEB34	B	1	1	0	0	2
PEC37	C	1	0	3	1	5
PEB40	B	1	3	0	1	5
CHB42	B	0	0	0	0	0
PEC44	C	1	0	3	1	5
PEB46	B	1	1	0	1	3
PLB48	B	3	1	0	3	7
PLC53	C	3	3	0	3	9

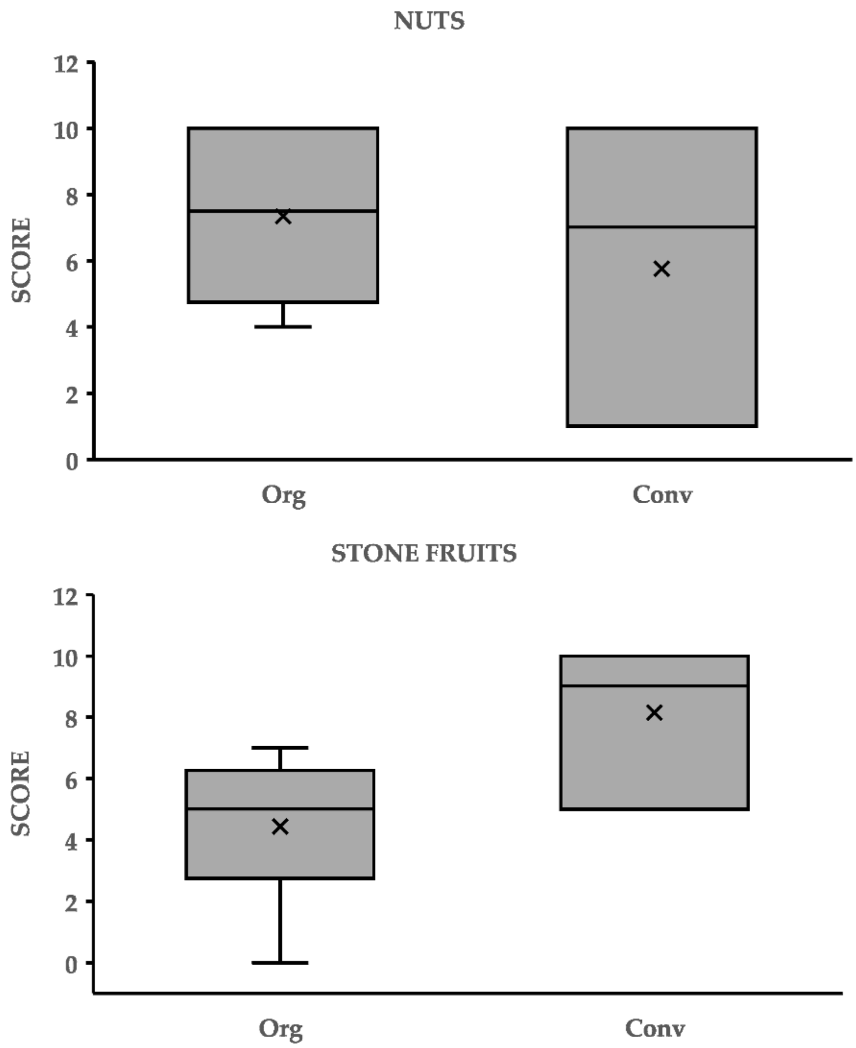

Figure 6. Boxplots for the score obtained to link ES to WEFC parameters.

4. Discussion

In this work, the four parameters of the WEFC nexus were evaluated with the help of four indicators, namely CF, WF, EI, and yield for organic and conventional mixed stone fruit and mixed nut orchards. A framework was developed to link the WEFC parameters to ES provided by these mixed orchards. This approach supports the application of low environmental impact agriculture schemes while accounting for ES maximization. For instance, the EU Green Deal (https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en, (accessed on 20 April 2022)) and the Farm to Fork Strategy (https://ec.europa.eu/food/horizontal-topics/farm-fork-strategy_en, (accessed on 20

April 2022)) have ambitious targets for input reduction and for climate change mitigation, thus easily applicable frameworks should be developed to quantify the benefits related to changes in management practices.

The yield is the most relevant indicator for food provision in agroecosystems. In the case of mixed nut orchards, the yield was significantly higher on conventional farms compared to organic farms. This can be related to factors such as the lower amounts and slower release of nutrients when organic fertilizers are used, in comparison to synthetic fertilizers, which are designed for optimum and fast release of nutrients to maximize yield [63,64]. However, for the indicators CF, WF, and EI, there was no statistically significant difference between organic and conventional mixed nut orchards, even though organic farms typically demonstrated lower values for these indicators. High GHG emissions, water, and energy use on some of the organic and conventional farms did not offer improved food provision. This indicates that there is potential for mitigation towards lower input farming [22,65]. The CF, WF, and EI (per kg of nuts) values were lower for the organic farms compared to the conventional farms, and this is due to lower input use (e.g., fertilizers). Therefore, organic mixed nut orchards are ideal for transitioning to reduced or zero emissions and sustainable water and energy use in agriculture. However, these systems result in lower food provision than conventional farms. Mixed nut farms provide higher calories per kg of food (Table 1) compared to other species despite their lower yield (kg ha^{-1}). Nut orchards typically occupy less fertile or marginal agricultural land compared to other crops (fruits, cereals, and vegetables).

Similarly, the yield (Mcal ha^{-1}) was significantly lower in the case of organic mixed stone fruit orchards when comparing them with conventional orchards. As already reported, increased inputs (e.g., water and fertilizers) in conventional and/or organic fruit production aim to maximize the yield, and therefore farmers' profit. Our data draw on the period from 2012–2014 when fertilizer and fuel prices were much lower than what was observed during and after the COVID-19 pandemic, where transportation costs (shipping) increased. Therefore, high prices for these inputs were not a factor for reducing the amounts applied compared to what was observed during the COVID-19 pandemic [66]. Lower or even zero inputs (e.g., fertilizers, pesticides, energy, and water) could be observed in mixed orchards, which typically cover family needs (not commercial). However, in this case, the yield could vary significantly over years, and it is something that is not preferred in commercial agriculture for food security reasons as well.

The carbon footprint (CF) was expressed as kg CO_2-eq per kg to compare with data from the relevant literature, where the lowest values were observed for field-grown vegetables (0.37 kg CO_2-eq kg^{-1}), field-grown fruit (0.42 kg CO_2-eq kg^{-1}), cereals (except rice), and pulses (0.50–0.51 kg CO_2-eq kg^{-1}) [67]. Slightly higher values for tree nuts were reported (1.20 kg CO_2-eq kg^{-1}). Rice had the highest CF among plant-based field grown crops (2.55 kg CO_2-eq kg^{-1}), slightly higher than fruit and vegetables from heated greenhouses (2.13 kg CO_2-eq kg^{-1}). In addition, CF values of 0.28–0.85 kg CO_2-eq kg^{-1} for grapes and 0.05–0.463 kg CO_2-eq kg^{-1} for aromatic plants produced in Cyprus have been reported [22,68,69]. The values reported in the current study, at 0.674 and 0.899 kg CO_2-eq kg^{-1} for organic and conventional nuts and 0.490 and 0.680 kg CO_2-eq kg^{-1} for organic and conventional stone fruit orchards, are within the range of the CF values reported for agricultural products [67]. However, the CF for nuts in our case is lower while the CF for stone fruits is higher than what is presented above. This is linked to the lower yield (kg ha^{-1}) and higher inputs in the case of stone fruit farms. On the other hand, nut farms in Cyprus seem to have lower inputs than what is typically reported in other countries. Attention should be given to the fact that a limiting factor in such comparisons is the different boundaries and functional units used in the LCA [67]. It should be stressed that we only account for GHG emissions related to fuel and fertilizer use (direct and indirect), leading to an underestimation of GHG emissions. However, energy and fertilizers, which we have considered, are key factors for GHG emissions from agriculture [21,22,68].

The water footprint (WF) was 393 L kg^{-1} for organic and 489 L kg^{-1} for conventional mixed nut orchards while these values were 680 and 237 L kg^{-1} for organic and conventional stone fruit orchards, respectively. These values are much higher than for grapes (rainfed) in Cyprus [70], highlighting the importance of using drought-resistant crops and cultivars towards sustainable farming (and water use) in Mediterranean islands. Water-demanding vegetables could reach irrigation water needs close to five times the annual rainfall in Cyprus (Litskas et al., unpublished data). A study on the average global (total) WF values for various crops reported values for sugar crops (197 L kg^{-1}), vegetables (322 L kg^{-1}), fruits (962 L kg^{-1}), cereals (1644 L kg^{-1}), pulses (4055 L kg^{-1}), and nuts (9063 L kg^{-1}) [71,72]. These values are comparable to our study as they refer to irrigation water. We observed lower WF values for nuts, which is due to lower irrigation water applied in the case of Cyprus.

Energy use (EI) for the case of organic and conventional mixed nut orchards was 1.763 and 3.762 MJ kg^{-1}, respectively. On organic and conventional mixed stone fruit farms, these values were 4.232 and 0.929 MJ kg^{-1}, respectively. The EI values are within the range of what is observed for medicinal and aromatic plants cultivated in Cyprus (0.18–5.8 MJ kg^{-1}, [22]). The EI increases when frequent tillage is applied due to higher fuel and machinery use [65,69]. The EI could increase more in intensively managed, conventional farms, with olive groves reaching 59 MJ kg^{-1} [73] while the value observed for organic olive groves was much lower at 17.5 MJ kg^{-1} [74].

Typically, WEFC parameters are expressed per kg of final product as this is the functional unit in the LCA approaches employed [67]. In our analysis, we have chosen to express and analyze our data per hectare of cultivated land. The yield for nut and stone fruit in Mediterranean areas varies due to pests and climate, but the farmers typically apply the same inputs (e.g., water, fertilizers, and energy) each year per hectare. Therefore, studying the WEFC and ES at the hectare basis might be preferable for selecting the crops from a land use perspective to minimize the environmental impacts and increase ES.

In the case of mixed nut orchards, GHG emissions per Mcal of food produced were not significantly correlated to soil parameters (organic matter, soil respiration, organic nitrogen, and aggregate size), AMF, and farm attributes (tree age and number of weed species). On the other hand, a significant correlation was observed for these parameters in the case of stone fruit (Figure 4). After using the stepwise regression process to remove some of the independent variables, tree age and soil aggregate mean weight diameter were identified as the most significant. GHG emissions were estimated based on fuel and fertilizer use as well as soil-related emissions. In the case of the mixed stone fruit orchards, these inputs were lower as the tree age increased. Therefore, the higher the tree age, the higher its capacity to explore the soil for nutrients and water. In addition, the yield also increases to reach a peak (kg per tree), which results in lower GHG emissions per Mcal of food compared to a younger tree, which is also less productive. Increased soil aggregate stability is a proxy for a better soil structure, favoring water, air, and heat transfer into the soil, thus contributing to increased soil respiration [75]. On the contrary, reducing the MWD of soil aggregates impacts water, air, and heat transfer in the soil, which could possibly lead to reduced soil respiration.

Cluster analysis was used to group mixed orchards according to CF, EI, WF, and food production, all expressed per ha of cultivated land. Regardless of the achieved yield, farmers apply the same practices every year (e.g., fertilizer application). Based on the centroids (Table 3) and for the mixed nut orchards, it was clear that increased food provision led to increases in EI, WF, and CF values due to increased inputs (water, fertilizers, and energy). However, most of the farms (55.6%) are characterized as belonging to the cluster with the lowest values regarding the WEFC parameters evaluated. This clearly demonstrates the capability of mixed nut orchards to be employed in low-input agriculture with reduced EI, CF, and WF values. Another finding is that the highest yield (MCal ha^{-1}) was not obtained after maximizing inputs (Table 3), which results in highest WF, EI, and CF values. This highlights the potential for reducing inputs in mixed nut orchards to improve environmental performance. However, it should be stressed that increased irrigation resulted in a higher yield. Since irrigation systems operate by using energy (mainly fuel), this results in increased EI and CF values. Similar results were obtained in the case of mixed stone fruit orchards. Most of the farms belong to the cluster with the lowest food production, which also has low irrigation water use in comparison to the other two clusters. Maximum yield was also not achieved with maximum inputs. This is important as in many cases the farmers prefer to maximize inputs to achieve the highest yield and income.

It should be also highlighted that carbon storage in plants and soil was not considered in the CF-related calculations. It is possible that the emissions on the studied farms are even lower if storage in plant biomass and soil is taken into consideration [76].

The score (indicative of ES provision) that was obtained after linking WEFC parameters to ES in mixed orchards was higher in organic mixed nut orchards compared to conventional orchards. Typically, this was related to lower EI, CF, and WF values and translates into a reduced impact on atmospheric composition and regulation, water cycle, and availability (Table 2). On the other hand, reduced yield in organic nut orchards leads to reduced food provision. This was the factor where organic mixed stone fruit orchards achieved a lower ES score than conventional orchards (Table 5). The ES score is in accordance with the cluster centroids and there are orchard examples (e.g., NUB10; APRC5) where higher yield can be achieved without increasing inputs.

It is typical that low EI, WF, and CF values are linked to lower yield. In this case, maximizing yield should not be the only target in Mediterranean mixed orchard systems as increasing yield negatively impacts ES. Intensive farming practices, implemented to increase yield, and environmental changes occurring on Mediterranean islands could impact the ability of the local agroecosystems to provide goods and services [34,77]. In contrast, organic mixed orchards in Mediterranean areas assist in soil degradation prevention, especially in mountainous areas where eco-geomorphology and specific land uses with less vegetation cover result in soil erosion [78]. Promoting reduced or no tillage and organic fertilization can benefit both soil quality and soil fertility [79].

Our results show that increased nutrient application in the soil is important for food provision as it increases yield. However, excessive use of chemical fertilizers (especially N) has negative impacts on water purification [80] and nutrient cycling, as well as climate and gas regulation [80–83]. A more serious issue is the loss of N fertilizer due to conversion to N_2O and the resulting increase of the CF of products. Regarding farm attributes, orchard size was similar in many cases, but trees were, in many cases, older on the conventional farms than on the organic farms. Nevertheless, it is typical for farmers in Cyprus and other countries to apply the same input amounts (e.g., fertilizers and agrochemicals) when the trees come to a full production phase, which was the case in the current work for both organic and conventional orchards.

Crop diversification is seen as an option to reduce the negative impacts of agriculture and to enhance agricultural ES [84]. Mixed orchards support crop diversification. Our results corroborate the findings of Demestihas et al. [34], that orchards have a high potential for ES provision and that agricultural management practices and farming systems affect ES.

The landscape in Mediterranean areas is influenced by agriculture that has generated a diversity of field and land use patterns [85–87]. This ranges from specific types, such as fruit orchards, irrigated or rainfed arable fields, livestock grazing systems, and natural vegetation to other more complex landscapes. From a management perspective, this work provides a framework for the selection of farming practices that continue to benefit landscape preservation and ES.

5. Conclusions

Mixed orchards in Mediterranean island and coastal areas are threatened by urbanization and abandonment. Therefore, our work provides insights into the contribution of such systems to ecosystem services (ES) provision and their link to the WEFC nexus. In the research herein, 39 mixed farms (organic and conventional) were selected for analysis and management practices and soil quality parameters were determined. The inputs and management practices were translated to EI, WF, and CF, and yield was also determined. A framework linking the WEFC parameters to ES was developed. The results of the study reveal the importance of considering ES and the WEFC nexus, as well as yield itself, towards sustainable agriculture in Mediterranean areas. However, these findings need to be further supported with monitoring data from such farms related to the ES provided. Nevertheless, the results of this work are important for managing mixed orchards and adopting practices that have the potential to support ES.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy12092224/s1, Figure S1: Plot of observed vs. predicted GHG emissions for the case of organic and conventional mixed stone fruit orchards; Figure S2: Classes obtained based on the values of the WEFC parameters for the mixed nut orchards. Green: 3 points; orange: 1 point; red: 0 points.; Figure S3: Classes obtained based on the values of the WEFC parameters for the mixed stone fruit orchards. Green: 3 points; orange: 1 point; red: 0 points. Table S1: Characteristics and attributes of the selected mixed orchards (location, system, main tree species, area, and tree age); Table S2: Soil parameters; Table S3: Emission factors for diesel and fertilizer production; Table S4: WEFC parameters for the mixed orchards and ES-related classification.

Author Contributions: Conceptualization, all authors; methodology, S.I., V.L, and I.N.V.; data curation, S.I. and V.L.; writing—original draft preparation, S.I., V.L. and I.N.V.; writing—review and editing, all authors; visualization, V.L.; supervision, I.N.V. and M.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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