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Contribution of Agro-Environmental Factors to Yield and Plant Diversity of Olive Grove Ecosystems (*Olea europaea* L.) in the Mediterranean Landscape

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Abstract: Olive cultivation (*Olea europaea* L.) is one of the most significant sources of income for agricultural areas in the Mediterranean basin, and the olive oil industry as well as the environmental protection are an important part of the Greek agricultural sector. Generalized Linear Models were applied in order to investigate the predictive strength of several biodiversity components and agro-environmental factors for yield and herbaceous plant diversity (species richness) in organic and conventional olive groves of Greece. Our study highlights an increase in yields of organic olive groves by increasing manure application and the earthworms' density. In the conventional olive groves, yields increase by increasing soil organic matter and the application of inorganic fertilizer N. Also, the herbaceous plant species richness increases with increasing the Shannon diversity index of herbaceous plants, the field area, the application of organic fertilizer K and the manure in organic olive groves. As for the conventional ones, herbaceous plant species richness increases with the increase of the application of inorganic fertilizer N. Moreover, some plant species could be regarded as indicators of the differently managed olive groves. Conclusively, this study contributes to the integration of biodiversity conservation with ecologically sustainable agriculture and conservation of agroecosystem. Finally, it could be utilized as a decision and management tool to the scientific and agricultural community reinforcing the knowledge about the agro-environmental impact in olive grove management systems.

Keywords: olive trees; yield; plant; management; environment; Mediterranean

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1. Introduction

A long history of human interaction can be found in the Mediterranean basin. Ancient civilizations such as Phoenicia and Egyptm and later, the Greece and Roman Empires, have formed the landscape and the biodiversity pattern of the area [1,2]. The Mediterranean biome is known to support high biodiversity, so the area is considered as a biological "hotspot" [2,3], as it also hosts a high percentage of endemic species. Many parameters of human prosperity, such as health, freedom of choice, security, socialization and necessities of life are directly or indirectly related to biodiversity—directly through ecosystem services, indirectly through supporting these ecosystems. It is also true that there are a lot of people having profited by transforming natural ecosystems into those dominated by human proving that biodiversity can be exploited [4].

It is a well-known fact that the cultivation of the olive tree has played a vital role as far as human nutrition is concerned. The edible fruits and their oil are known for their beneficial properties and play an important part in our diet. Therefore, olive trees (*Olea europaea* L.) are probably the most financially important cultivated trees of the Mediterranean basin and their produce has been highly rated since antiquity. Since antiquity, olive oil has had a variety of uses (cooking, oil-lamps) and is even for its medicinal properties [5–8]. We find nearly 95% of the total number of the existing olive trees worldwide (800 million on 8.6 million hectares) in the Mediterranean basin [9]. Spain comes first, producing 1,600,000,000 Mg of olive oil per year, Italy follows with 400,000,000,000 Mg, and Greece comes third with 300,000,000,000 Mg per year, representing the 67%, 17% and 12% of the total European production, respectively [10]. Another Greek product is the table olive, the production of which reaches 900,000,000,000 Mg per year. Greece comes first in the consumption of olive oil, with over 25 Kg per person annually versus 15 Kg per person in Spain and 12 Kg per person in Italy [9].

Nowadays, while most olive groves are conventionally cultivated with the use of fertilizers, herbicides, and pesticides, there is an increasing realization of the problems stemming from this conventional farming. That is the reason why organic farming is gaining more and more ground in the belief that it improves public and environmental health [11]. Natural ecological processes together with an adjusted to local conditions biodiversity, are the basis of organic farming [12].

Biodiversity can be considered as the foundation of all ecosystem services to which human well-being/prosperity is linked, providing agricultural, economic, and health benefits. This variability among living organisms, and especially its indicators, consist one valuable and fundamental tool of the conservationists for taking immediate action against biodiversity loss of ecosystems [13]. Herbaceous plants are being used as indicators and play a crucial role in functioning ecosystems. Apart from being a source of food and medicinal compounds, they may also provide raw materials for many industries. In general, plant life is the balance for any ecosystem as it protects watersheds, compromises erosion, moderates the climate, and provides shelter/habitat for a lot of animal species. The capacity to support a wide variety of habitat and species is one of the major ecological factors in the agricultural landscape. Therefore, it is clear that any change in the agricultural landscape can directly affect both ecology and biodiversity resulting in proportional changes of natural resources and ecosystem services. We have a kind of “chain reaction”, as ultimately, natural resources and ecosystem services have a direct impact on what humanity can benefit from the landscape [14].

A key scientific issue concerning ecology and conservation biology has to do with establishing the factors which govern biodiversity. This knowledge enables us to counteract changes in the environment that would be harmful to both flora and fauna. In the past few decades, we have accumulated substantial evidence displaying the fact that the patterns in biodiversity, mostly analyzed at the level of species, often depend on the spatial scale considered [15]. Several recent studies have focused on various aspects of biodiversity research concerning various aspects of organisms, such as: taxonomic relationships [16,17], growth [18–20], form [21,22], adaptation [21,23,24] and function [25–27]. It is crucial to try and understand the factors responsible for the rich “universe” of organisms within an ecosystem [28–31] because biodiversity is the variability among all living organisms. Analysis and synthesis of biodiversity patterns along with the existing environmental and human factors are indispensable tools for “decoding” biodiversity and for applying any relevant methodology in order to protect and conserve it. Although these studies have led to a better understanding of the functions of biodiversity, the effects of biodiversity components and agro-environmental factors to yield and herbaceous plant diversity of olive ecosystems which are important to the integration of biodiversity conservation with ecologically sustainable agriculture, have been scarcely studied.

The main aim of our study was: (a) to test the potential importance of several biodiversity components (i.e., the cover of herbaceous and woody plants, isopods and earthworms, etc.) and the agro-environmental factors (i.e., soil pH and humidity, fertilizers, etc.) concerning yield and plant diversity. This testing concerns each management system of olive cultivation (*Olea europaea* L.), which will help farmers adopt the right practices leading to more sustainable olive production and (b) to determine the relations found between herbaceous plant species and management systems by using the Indicator Value Analysis

(IndVal) in order to identify possible indicator-species for specific olive grove management systems.

2. Materials and Methods

2.1. Study Area

The present study was carried out and conducted in 10 organic (O1-O10) and 10 conventional (C1-C10) olive groves], during two consecutive years, 2009 and 2010, in western Magnesia Prefecture of central Greece (39°03′12.05″ N, 22°57′11.84″ E) (Figure 1).

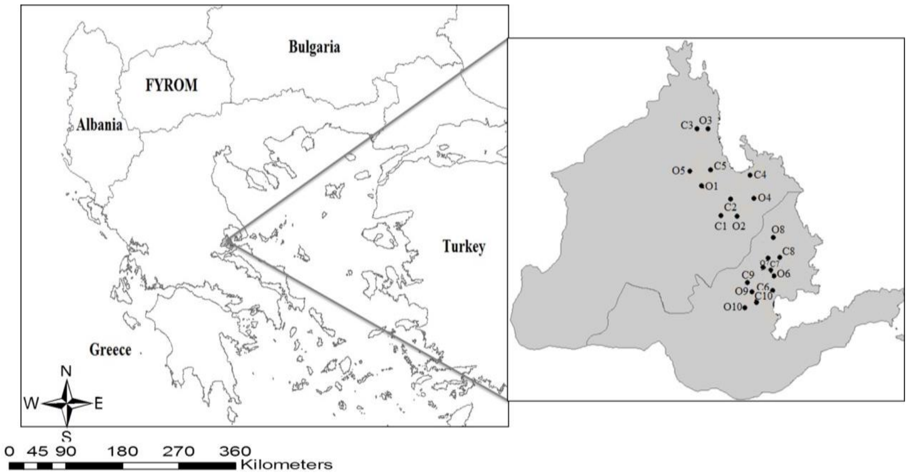

Figure 1. Study area.

The study area is included in the *Quercetalia ilicis* vegetation zone and *Quercion ilicis* and *Oleo-ceratonium* subzones [32]. Among the cultivated olive groves there is a small percentage (10%) of abandoned ones, while the rest of the area (35%) is covered by maquis such as *Olea europaea var. sulvestris* (Olive), *Quercus coccifera (Kermes oak)*, *Arbutus unedo* (Strawberry tree), *Pistacia lentiscus (Mastic tree)* and *Rubus fruticosus (Blackberry)*, and meadows can be found all around. In addition, around the fields there are meadows.

The climate is typical Mediterranean with relatively cold and wet winters, and hot, dry summers. The average temperature is 16.8 °C, with July as the warmest month and January-February the coldest. The average annual rainfall reaches 490 mm (National Meteorological Service of Greece). The characteristics and management practices applied to the organic and conventional olive groves are presented in Table 1.

Table 1. General characteristics and applied management practices to the organic and conventional olive groves (Amfissa variety) in central Greece.

	Organic	**Conventional**
Average field size (ha)	13.83	15.5
Average number of olive trees per hectare	200	200
Age of olive groves (years)	~150–170	~150–170
Years of enrolment	1997	
Average olive production (kg/tree)	48.20	51.00
Manure (kg per tree)	50	
Inorganic fertilizer N (kg per tree)		1.5–2
Inorganic fertilizer K (kg per tree)		1.5–2
Organic fertilizer K (kg per tree)Weed control	2–3Grass cutting	Herbicide
Irrigation application	No	No

2.2. Sampling

Herbaceous plant species were surveyed in spring season in organic and conventional olive groves. The sampling of herbaceous species was carried out by the Line Point

Method [33] (140 vegetation lines in organic and 140 in conventional olive groves totally was measured). Thereby herbaceous plant species richness was estimated. For determination of the plant samples used the "Flora Europaea" [34,35], the "Flora Hellenica" [36] and the Vascular plants of Greece: An annotated checklist [37,38]. Several important biodiversity components such as cover and density of woody plants, isopods and earthworms (see Appendix A, Tables A1–A5), and agro-environmental factors such as fertilizer, soil pH, and humidity that might affect yield and herbaceous plant species richness were evaluated.

2.3. Statistical Analyses

The study was carried out in a completely randomized design with 10 replicates. The Kolmogorov–Smirnov and Shapiro–Wilk's tests for the confirmation of the normal distribution of data were used. The validity of the homogeneous variance assumption was investigated by Bartlett's test. When normalization was necessary, the [log(x + 1)] transformation and inverse hyperbolic sine transformation when X has 0 values were used [39]. All the above tests were performed before each analysis.

Generalized Linear Models (GLMs) are one of the most widely used statistical methods. We used GLM because is most commonly used to model these data, so we focused on models for this type of data. GLM were used to analyze the agro-environmental factors, explaining most variance of yield and herbaceous plant species richness in olive grove management systems [40–42].

Because count data such as yield and plant species richness can never be less than zero, the assumption of ordinary least-squares regression is likely to be broken [43]. We assumed yield and plant species richness to be Poisson-distributed random variables and utilized a logarithmic link function in a Generalized Linear Model [44].

Aiming at decreasing the large number of initial variables in the model (n = 27), we first tested the collinearity among the several variables. The highly correlated ones were defined by using a cut level of $R^2 = 0.9$ (corresponding to the variance factor 10). The best performing single variable model based on Akaike's Information Criterion (AIC) was used as a start with the number of the rest increasing, until the change in explained deviance D^2 was less than 1% [45]. Each of the best n-variable models concluded by comparing all possible n-variable combinations. In order to define the final models, backward elimination based on AIC was used, testing separately linear and quadratic terms, while insignificant parameters were excluded [46]. The changes resulting in the explained deviance D^2 were indicators of the parameter's-variable's performance. The models' robustness was repeatedly evaluated with 10-fold cross-validations. For robust results, the mean of 100 internal cross-validations was used [47,48].

The model coefficients had been taken from the model of robust standard errors and the formula for the model is the below:

$$Y = \beta_1 X_1 + \beta_2 X_2 + \ldots .. + \beta_p X_p + \beta_0 \quad (1)$$

Y = the dependent variable (also called the predicted variable).
$\beta_1, \beta_2 \ldots \beta p$ = a weight (also called a coefficient). Determines how much weight one variable contributes to the model. If everything in the equation holds constant, b_0 gives the predicted change in Y for a unit change in X.
$X_{1,2 \ldots p}$ = a variable.
β_0 = the intercept—always a constant.

All statistical analyses were performed using R Statistical Software (version 3.5.0) [49].

Characteristic plant species indicators of organic and conventional olive groves were assessed by the Indicator Value index (IndVal). The IndVal method of a species has long been the most popular measure, commonly used in ecology, to express species importance in a community. IndVals were calculated for each herbaceous plant species on the basis of its abundance and frequency of occurrence in samples assigned to each olive grove management system. The Indicator Value index takes values between 0 and 100. Only significant IndVals (identified with Monte Carlo statistics) (Indval > 50%) were considered [50]. The characteristic plant species takes the highest value (100) when all individuals of a plant species are found in a single management type (high specificity) and when the species occurs at all forms of this type (high fidelity) [51]. This analysis was accomplished with the application of the IndVal software (for a detailed description of the mathematical background for IndVal, see Dufrene and Legendre 1997) [52].

3. Results

3.1. Factors Influencing Yield of Olive Grove Management Systems

The Generalized Linear Models built for yield of organic and conventional olive groves (Table 2) showed a very good predictive ability (as shown by the respective adjusted R^2) (Table 3). Especially, the models presented in Table 3 include two variables, for both organic and conventional olive groves, which account for 88% and 85% of the variance (based on adj. R^2) of olive grove yields, respectively. More specifically, the yields of organic olive groves increase as the application of manure and the density of earthworms increase, while the yields of conventional olive groves increase with the increase of soil organic matter and inorganic fertilizer applications (N).

3.2. Factors Influencing Herbaceous Plant Species Richness of Olive Grove Management Systems

The herbaceous plant species of the study olive groves comprises 107 species belonging to 93 genera related to 35 families. The herbaceous plant species recorded in organic olive groves was 101 while in conventional olive groves was 74 species (see Table A2).

The model for herbaceous plant species richness in organic olive groves comprises four variables [herbaceous plant Shannon diversity index (the Shannon (Sd) plant diversity index was examined by Species Diversity and Richness IV software (Seaby and Henderson 2006), in each olive grove management system [(for a detailed description of the mathematical background for Sd index, see Seaby and Henderson, (2006)] [53], field area, organic potassium fertilization, and manure application] (Tables 4 and 5). The model explains a fairly good percentage of the whole variability of the dependent variable and shows that herbaceous plant species richness increases significantly with increasing Shannon diversity index of herbaceous plants, field area, application of organic, potassium fertilization, and manure application to organic olive groves (Table 5).

Table 2. Selection of model variables.

Organic Olive Groves				
Variable Names or selection procedure	AIC	Residual deviance	D^2	Percentage change in D^2
Ed	33.900	4.950	0.605	–
Ed + Man	27.949	4.300	0.610	0.800
All variables	30.220	3.270	0.620	–
Conventional Olive Groves				
Variable Names or selection procedure	AIC	Residual deviance	D^2	Percentage change in D^2
Om	50.008	7.726	0.685	–
Om + IfN	25.548	7.167	0.690	0.875
All variables	40.854	6.894	0.725	–

Note. A change in deviance $D^2 < 1\%$ was used as a stopping criterion [48]. Ed: Earthworms density, Man: Manure, Om: Organic matter, IfN: Inorganic, nitrogen rich fertilizer.

Table 3. Factors influencing yield (Y variable) in organic and conventional olive groves.

Variables (X1, X2)	Coef. (Estimate)	Robust SE	t	Adj.R^2	Likelihood Ratio χ^2	BIC	Wald Chi-Square	F
Organic Olive Groves								
				0.889	24.524	29.159		37.157
(Intercept)	14.675	4.933	2.974 *				8.853	
Ed	0.034	0.009	3.777 *				13.473	
Man	2.787	0.623	4.473 *				19.970	
Conventional Olive Groves								
Variables (X1, X2)	Coef. (Estimate)	Robust SE	t	Adj.R^2	Likelihood Ratio χ^2	BIC	Wald Chi-Square	F
				0.850	749.533	26.456		374.766
(Intercept)	1.428	1.796	0.795 *				0.632	
Om	1.857	0.818	2.270 *				5.142	
IfN	4.674	0.236	19.805 *				390.523	

Note. Ed: Earthworms density, Man: Manure, Om: Organic matter, IfN: Inorganic, nitrogen rich fertilizer. * $p < 0.05$.

Table 4. Selection of model variables.

Variables Names or selection procedure	AIC	Residual deviance	D^2	Percentage change in D^2
Organic Olive Groves				
Sd	48.840	3.530	0.750	–
Sd + OrgK	47.550	3.400	0.770	2.666
Sd + OrgK + Man	45.230	3.330	0.778	1.038
Sd + OrgK + Man + Fs	20.115	3.110	0.785	0.899
All variables	42.000	3.090	0.791	–
Conventional Olive Groves				
Variables Names or selection procedure	AIC	Residual deviance	D^2	Percentage change in D^2
IfN	56.020	5.330	0.533	–
All variables	54.000	4.100	0.635	

Note. A change in deviance $D^2 < 1\%$ was used as a stopping criterion [48]. Sd: Shannon plant diversity index, OrgK: Organic, potassium rich fertilizer, Man: Manure, Fs: Field size, IfN: Inorganic, nitrogen rich fertilizer.

Table 5. Factors influencing herbaceous plant species richness (Y variable) in organic and conventional olive groves.

Variables (X1, X2 ...)	Coef. (Estimate)	Robust SE	*t*	Adj.R^2	Likelihood Ratio χ^2	BIC	Wald Chi-Square	F
Organic Olive Groves								
				0.985	54.600	21.931		292.621
(Intercept)	20.692	1.076	19.23 *				369.538	
Sd	5.808	0.426	13.633 *				185.533	
OrgK	0.109	0.02	5.45 *				14.353	
Man	2.231	0.367	6.07 *				36.874	
Fs	1.912	0.116	16.482 *				267.427	
Conventional Olive Groves								
Variables (X1, X2 ...)	Coef. (Estimate)	Robust SE	*t*	Adj.R^2	Likelihood Ratio χ^2	BIC	Wald Chi-Square	F
				0.456	7.268	56.928		8.548
(Intercept)	57.703	17.800	3.241 *				10.509	
IfN	4.301	1.778	2.419 *				5.484	

Note. Sd: Shannon plant diversity index, OrgK: Organic, potassium rich fertilizer, Man: Manure, Fs: Field size, IfN: Inorganic, nitrogen rich fertilizer. * $p < 0.05$.

The model for the herbaceous plant species richness in conventional olive groves consists of one variable (inorganic, nitrogen rich fertilizer) that accounts for nearly half of the total variability of the dependent variable (Tables 4 and 5). Therefore, herbaceous plant species richness was significantly and positively correlated with inorganic fertilizer application (Table 5).

3.3. Identifying Indicator Plant Species in Olive Grove Management Systems

The IndVal procedure which was used to evaluate possible indicator species in herbaceous plant communities showed that 14 species (*Leontodon tuberosus (*Bulbous dandelion*)*, *Muscari comosum* (Tassel hyacinth), *Ferulago nodosa* (Fennel), *Salvia verbenaca (*Vervian sage*)*, *Raphanus raphanistrum* (Jointed charlock,), *Fumaria officinalis* (Wild radish), *Cyclamen graecum* (Greek cyclamen), *Erodium cicutarium* (Common crowfoot), *Anthemis arvensis* (Corn chamomile), *Aegilops ovata* (Geniculate goatgrass), *Geranium robertianum (*Herb-robert*)*, *Avena barbata (*Slim oat*)*, *Convolvulus althaeoides* (Mallow bindweed), and *Pallenis spinosa (Spiny starwort)*, could be regarded as eurytopic (Table 6. Also, ten herbaceous plant species (Indval > 50%) [*Setaria verticillata (Bristly foxtail)*, *Medicago lupulina* (Black Medick), *Trifolium arvense (*Rabbitfoot clover*)*, *Malva sylvestris (*Creeping charlie*)*, *Matricaria recutita (*German chamomile*)*, *Sinapis arvensis* (Wild mustard), *Papaver rhoeas* (Flanders poppy), *Hordeum bulbosum (Bulbous barley)*, *Trifolium campestre* (Hop clover), and *Anagallis arvensis* (Scarlet pimpernel)] were recorded in organic olive groves while one herbaceous plant species (*Sonchus oleraceous*- Common sowthistle) was recorded in conventional ones. These species should be regarded as «characteristic indicator species» of the organic and conventional olive groves.

Table 6. IndVal analysis for herbaceous plant species.

Species	IndVal (%)	Management System
Leontodon tuberosus	97.5	Olive grove management systems
Muscari comosum	97.5	Olive grove management systems
Ferulago nodosa	92.5	Olive grove management systems
Salvia verbenaca	90	Olive grove management systems
Raphanus raphanistrum	87.5	Olive grove management systems
Fumaria officinalis	85	Olive grove management systems
Cyclamen graecum	75	Olive grove management systems
Erodium cicutarium	72.5	Olive grove management systems
Anthemis arvensis	70	Olive grove management systems
Aegilops ovata	67.5	Olive grove management systems
Geranium robertianum	67.5	Olive grove management systems
Avena barbata	60	Olive grove management systems
Convolvulus althaeoides	57.5	Olive grove management systems
Pallenis spinosa	57.5	Olive grove management systems
Setaria verticillata	73.77	Organic olive groves
Medicago lupulina	77.87	Organic olive groves
Trifolium arvense	77.67	Organic olive groves
Hordeum bulbosum	63.83	Organic olive groves
Malva sylvestris	74.84	Organic olive groves
Papaver rhoeas	57.55	Organic olive groves
Trifolium campestre	56	Organic olive groves
Anagallis arvensis	55.46	Organic olive groves
Matricaria recutita	89.41	Organic olive groves
Sinapis arvensis	51	Organic olive groves
Sonchus oleraceous	72.61	Conventional olive groves

4. Discussion

4.1. The Contribution of Agricultural and Environmental Factors in the Yields of Organic and Conventional Olive Groves

The yields of organic olive groves were found to be positively affected by the application of manure and the earthworms' density. This is probably due to the fact that the application of manure in organic olive groves contributes to soil fertilization, adding organic matter and nutrients (nitrogen, phosphorus, and potassium), and improving the physical and chemical characteristics of the soil, thus enhancing the growth of olive groves. Organic matter is essential both for the nutrition of the olive trees and for an efficient production system [54]. As for the beneficial effect that the increased earthworm's density has on the yields of organic olive groves, this is probably due to the fact that earthworms decompose organic matter and recycle nutrients by enriching the surface soil through their feces. Thus, earthworm feces are rich in nutrients (carbon, nitrogen, and phosphorus) [55], which as mentioned above are important factors that determine the growth and fruiting of olive trees. According to the literature, earthworms are the most important component of soil fauna, which benefit the formation, conservation soil structure, and fertility [56].

The yields of conventional olive groves were observed to be favored, both by the organic matter of the soil and by the application of inorganic fertilization N. As mentioned above the organic matter is necessary for an efficient production system of the olive groves. Organic matter in the soil plays a central role in regulating the availability of N, P, and K and can also act as a chelating compound, making some micronutrients more available to the roots of olive trees in the form of complexes [57]. Finally, inorganic nitrogen fertilization has been shown to continuously increase yields of olive groves, but only when the N in the leaves is below the adequacy threshold [58].

4.2. The Role of Agricultural and Environmental Factors in the Yields of Organic and Conventional Olive Groves

4.2.1. Organic Olive Groves

In the research area it was observed that the Shannon diversity index of the herbaceous plants, the area of the field, the application of organic fertilization K and manure application were considered the best indicators of the herbaceous plant species richness in organic olive groves.

The above results for the herbaceous plant species richness are in line with the theory that claims that the correlations between herbaceous plant species richness and diversity are simple, positive and powerful [59]. Tuomisto and Ruokolainen (2005), Sulivan and Sulivan (2006), and Solomou and Sfougaris (2011) [60–62] found in their research a positive correlation between the species richness and the Shannon diversity index of herbaceous plants in orchards, olive groves and natural ecosystems.

It is documented that organic fertilizer is one of the factors affecting the herbaceous plant diversity [63]. In the organic olive groves of the research area the application of manure and organic fertilizer K increased the herbaceous plant species richness in the following ways: it increases the soil organic matter, it contributes to its fertility by adding nutrients such as nitrogen, it helps to retain its moisture, reduces temporary stress due to lack of moisture, and contains varying amounts of viable herbaceous seeds that promote the preservation and promotion of high herbaceous plant diversity [64,65].

Also, the application of manure in agro-ecosystems enriches the soil with organic matter that very easily affects the measurable functions and processes of the soil. Especially, it is a source of nutrients for plants helping to increase the herbaceous plant species richness and provides an energy substrate for soil organisms [66]. In addition, soil organic matter has a huge impact on various physical properties of the soil, such as the amount of water available for plant growth [67]. Pleasant and Schlater (1994) [68] found that organic fertilizer increases the herbaceous plant species richness by adding plant species, while Yang et al. (2009) [69] that soil parameters, such as soil organic matter, related to the diversity of species of wild fauna and flora. In contrast, Cook et al. (2007) [70] found that the application of manure only as fertilizer did not affect the richness and diversity of herbaceous plants during the first year after its application.

As for the relationship between the area of the field and the herbaceous plant species richness, it probably follows one of the rules of ecology according to which as the area increases, the species richness tends to increase, regardless of the classification group or type of the ecosystem [71,72]. The results of this study are in line with those of Jacquemyn et al. (2002) [73] and Bruun (2005) [74], who found a positive correlation between the herbaceous plant species richness and their extent in natural ecosystems. In contrast, Belfrage et al. (2005) [75] and Marini et al. (2009) [76] found a negative correlation between field area and herbaceous plant diversity in rural landscapes.

4.2.2. Conventional Olive Groves

Only one variable (inorganic fertilization N) had a significant effect on the herbaceous plant species richness in conventional olive groves. Thus, herbaceous plant species richness increases with increasing the application of inorganic nitrogen fertilization. Regarding the above role of total soil N, a possible interpretation is that of all the nutrients that are applied to the soil, this is the key element that has the most significant effect on the growth and development of cultivated and native plants, and which is the most important limiting factor of growth and yield. The vital role of nitrogen in plants is due to the results of the following facts: it is a structural component of the chlorophyll molecule that is an essential factor for the production and utilization of carbohydrates, is a component of enzymes, a stimulant of plant growth and function, a component of amino acids, which are the building blocks of proteins, and promotes the intake and utilization of other nutrients [77].

Due to the management practices of conventional agriculture and soil erosion which leads to the loss of nutrients (N, P, K) from the soil, it is necessary to apply inorganic fertilizers that aim to enrich the soil with these components. Therefore, in the present study the positive effect of inorganic N fertilization on the herbaceous plant species richness could be attributed to the theory which is based on the model of Al-Mufti et al. (1977) [78] and Grime (1979) ("humped-back curve") [79] and predicts high species richness when availability nutrients are medium. Under these conditions, a small number of competing species tend to dominate the vegetation, leading to the exclusion of slow-growing species.

Grime (1979) [79] described the relationship between species richness and productivity as a curved curve with low species richness at very high and low productivity values. The shape of the curve appears like this, because only a few species adapt to these extremely poor nutrient conditions and a few dominant species prevail in all other conditions that have a high level of resources. Studies conducted on a wide range of plant communities have verified the shape of the curve and have shown not only the maximum species richness, but also the maximum species variability observed at medium productivity levels [80,81]. The results from the present study on potassium are inconsistent with the results of various researchers [82,83] who have shown that nutrients are an important factor in the herbaceous plant species richness in agro-ecosystems. However, many studies have shown that increasing productivity, through inorganic fertilizers N, P, and K, is accompanied by a decrease in the species richness of the meadows [84,85].

4.3. Typical Herbaceous Plant Species

According to IndVal analysis, the herbaceous plant species Setaria verticillata, Medicago lupulina, Trifolium arvense, Hordeum bulbosum, Malva sylvestris, Papaver rhoeas, Trifolium campestre, Anagallis arvensis, Sinapis arvensis, and Matricaria recutita were recorded as "characteristic indicator species" in the organic olive groves. S. verticillata is a species found in orchards, olive groves and vines. It prefers warm, moist, and rich in organic matter, nutrients (e.g., potassium and magnesium) and relatively neutral pH, clay or sandy loam soils. It grows in well-lit but also in moderately shaded areas. M. lupulina grows in crops, in well-lit but also in moderately shaded moist areas with slightly acidic to weakly alkaline conditions and moderate amounts of nutrients in the soil. It also prefers clay or sandy loam soils. T. arvense grows in olive groves, vineyards and orchards. It needs light and moist sites with slightly acidic conditions and moderate amounts of nutrients and organic matter in the soil [86–89]. T. campestre is found in olive groves, ditches, and stony sites. It grows in well-lit and semi-shaded areas with slightly acidic, moist, and nutritious soils. H. bulbosum prefers sandy and loamy, nutrient-rich, and moderately moist slightly acidic to slightly alkaline soils. It grows in well-lit but also moderately shaded wet areas [86–89]. M. sylvestris is the most common type of mallow in agricultural ecosystems. It is often found in high density in olive groves, other orchards or vineyards. It prefers warm and moist soils, as well as soils rich in nutrients and organic matter. Also, it requires high light intensity, weak basic conditions (7.1–7.6) and high soil fertility. P. rhoeas prefers clay and loamy, moist and nutrient-rich soils. It is an indicator plant of non-acidic soils. A. arvensis is found in orchards and arboreal crops and is characterized by broad adaptability and moderate nutrient requirements and soil fertility. S. arvensis prefers well-ventilated, light-rich, nutrient-rich soils. It is an indicator plant of non-acidic soils. M. recutita is found both in cultivated fields and in uncultivated areas. It prefers clay, sandy loam, rich in nutrients but poor in calcium and moderate in moisture, acidic to alkaline [86–89].

In conventional olive groves the plant species *S. oleraceus* emerged as an indicator species. *S. oleraceus* is a plant that occurs in uncultivated areas, orchards, olive groves and areas with trees. It prefers clay and sandy soils with nitrogen adequacy. It grows in well-lit but also in moderately shaded areas and is a plant of warm areas (average annual temperature 14 °C) and soils with slightly acidic to alkaline conditions [86–89].

5. Conclusions

The findings of the present study provide useful information on the impact of certain biodiversity components and agro-environmental factors on olive grove yields and can help farmers adopt the right practices leading to more sustainable olive production. More specifically, the results suggest that yields increase with increased manure application and the density of earthworms in organic olive groves while the yields of conventional ones increase by increasing soil organic matter and the application of inorganic fertilizer N. Earthworms, thus, might be used to enhance indirect the olive groves production and are evaluated as possible indicators for monitoring in other similar Mediterranean ecosystems as well.

We must also consider the fact that the herbaceous plant species richness increases by increasing Shannon diversity index of herbaceous plants, the field area, the application of organic fertilizer K and manure in organic olive groves. Herbaceous plant diversity could be utilized as the best candidate to enhance biodiversity components such as herbaceous species richness and evaluated as possible indicator for environmental monitoring also in other similar ecosystems. As regard the conventional ones, herbaceous plants increase with the increase of the application of inorganic, nitrogen rich fertilizer.

Moreover, the «indicator plant species» that have emerged in olive grove management systems (S. verticillata, M. lupulina, T. arvense, H. bulbosum, M. sylvestris, P. rhoeas, T. campestre, A. arvensis, S. arvensis, and M. recutita were recorded as indicator species in the organic olive groves and S. oleraceus in conventional ones) can be used as indicators of environmental conditions, which would otherwise be very difficult, costly, and time consuming to measure. It is noteworthy that they can be monitoring tools in the management of olive grove ecosystems and provide useful information to farmers, agronomists, land managers and the scientific community. Furthermore, the findings revealed useful information towards understanding the functions of these ecosystems and the broader design of biodiversity management practices in managed ecosystems and lead to a more sustainable olive production.

Further research will focus on the evaluation of the environmental impacts of the olive-oil production chain. This effort will be made in order to identify the critical issues and suggest improvements for increasing environmental sustainability and competitiveness of olive cultivation in areas particularly susceptible to human pressure.

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Appendix A

Table A1. Mean (±Standard Deviation) of agricultural and environmental factors in organic and conventional olive groves.

Variables	Sampling Methods	Organic Olive Groves	Conventional Olive Groves
Herbaceous plant cover (Hpc) (%)	Line point	84.40 ± 5.96	73.80 ± 5.36
Shannon's diversity of herbaceous plants (Sd)	Line point	2.63 ± 0.06	2,37 ± 0,04
Herbaceous plant biomass (Hpb) (gr/0.25 m^2)	0.25 m^2 plot	69.40 ± 5.21	58.80 ± 4.39
Woody plant density (Wpd) (individuals/100 m)	10*10 m plot	7.14 ± 0.42	4.25 ± 0.64
Earthworm density (Ed) (individuals/0.25 m^2)	0.25 m^2 plot	25.24 ± 11.69	4.20 ± 1.54
Isopod density (Id) (individuals/100 trap days)	Pitfall traps	9.3 ± 2.1	6,86 ± 2.3
Farm size (Fs) (ha)	GPS (Garmin eTrex Venture HC)	138.30 ± 193.79	155.00 ± 109.29
Altitude (Al)(m)	GPS (Garmin eTrex Venture HC)	80.34 ± 51.71	62.85 ± 47.19
Slope (Sl) (%)	Clinometer (Suunto Tandem)	29.65 ± 21.05	23.96 ± 17.97
Air temperature (At) (°C)	Digital Thermo-Hygrometer, TFA	17.49 ± 1.77	18.66 ± 1.47
Relative humidity (Rh) (%)	Digital Thermo-Hygrometer, TFA	69.01 ± 8.65	63.85 ± 6.25
Organic fertilizer K (OfK) (kg/m^3)	Questionary	81.00 ± 14.49	
Inorganic fertilizer N (IfN)(kg/m^3)	Questionary		9.51 ± 0.74
Inorganic fertilizer K(IfK) (kg/m^3)	Questionary		20.64 ± 2.58
Manure (Man) (kg)	Questionary	9.80 ± 0.42	
* Herbicide (Her)	Questionary	0	1
Sand (San) (%)	Cylindrical sampler	51.00 ± 12.57	55.80 ± 8.09
Clay (Cl|) (%)	Cylindrical sampler	23.60 ± 8.94	17.60 ± 5.96
Silt (Sil) (%)	Cylindrical sampler	25.40 ± 6.22	26.60 ± 6.46
pH (pH) (%)	Cylindrical sampler	7.01 ± 1.14	6.77 ± 0.75
CEC (CEC) (meq/100 gr)	Cylindrical sampler	18.50 ± 6.88	12.55 ± 4.23
$CaCO_3$ ($CaCO_3$)(%)	Cylindrical sampler	5.37 ± 9.43	2.02 ± 4.80
P (P) (mg/kg)	Cylindrical sampler	4.36 ± 1.80	2.75 ± 0.48
K (K) (mg/kg)	Cylindrical sampler	192.95 ± 186.45	108.15 ± 52.69
Organic matter (Om)(%)	Cylindrical sampler	3.46 ± 0.93	0.82 ± 0.16
C/N (C/N)	Cylindrical sampler	9.08 ± 3.36	4.83 ± 2.45
Bulk density (Bd) (gr/cm^3)	Cylindrical sampler	0.99 ± 0.04	1.30 ± 0.09

* Herbicide (0: Absence, 1: Presence).

Table A2. Herbaceous plant species recorded in organic and conventional olive groves. Species nomenclature based on Dimopoulos et al. (2013; 2016) [37,38].

Species	Family	Organic Olive Groves	Conventional Olive Groves
Aegilops geniculata	Poaceae	+	+
Aira elegantissima		+	+
Alopecurus myosuroides		+	+
Briza maxima		+	+
Bromus tectorum		+	
Cynosurus echinatus		+	
Dactylis glomerata		+	+
Gaudinia fragilis		+	+
Hordeum bulbosum		+	+
Hordeum murinum		+	+
Lagurus ovatus		+	
Lolium perenne		+	
Piptatherum miliaceum		+	+
Psilurus incurvus		+	+
Setaria verticillata		+	+
Sorghum halepense		+	+
Avena barbata		+	+
Anthemis arvensis	Asteraceae	+	+
Anthemis chia		+	+
Calendula arvensis			+
Carduus pycnocephalus		+	+
Glebionis segetum		+	+
Cichorium intybus		+	
Crepis rubra		+	+
Crupina crupinastrum		+	+
Onopordum acanthium		+	
Onopordum illyricum		+	
Onopordum tauricum		+	
Matricaria recutita		+	+
Leontodon tuberosus		+	+
Sonchus oleraceus		+	+
Xanthium spinosum		+	
Lupinus angustifolius	Fabaceae	+	+
Medicago lupulina		+	+
Trifolium angustifolium		+	+
Trifolium arvense		+	+
Trifolium campestre		+	+
Vicia cracca			+
Capsella bursa-pastoris	Brassicaceae	+	
Raphanus raphanistrum		+	+
Rapistrum rugosum		+	
Parietaria officinalis		+	
Sinapis arvensis		+	+
Alcea biennis	Malvaceae	+	+
Malva sylvestris		+	+
Arisarum vulgare	Araceae	+	+
Arum maculatum		+	
Dracunculus vulgaris		+	
Anemone coronaria	Ranunculaceae	+	
Anemone pavonina			
Asphodeline lutea	Asphodelaceae	+	
Asphodelus aestivus		+	+
Asphodelus ramosus		+	

Table A2. *Cont.*

Species	Family	Organic Olive Groves	Conventional Olive Groves
Daucus carota	Apiaceae	+	+
Eryngium campestre		+	+
Orlaya daucoides		+	+
Orlaya grandiflora		+	
Oenanthe pimpinelloides		+	
Pallenis spinosa		+	+
Smyrnium rotundifolium		+	
Smyrnium perfoliatum		+	+
Ferulago nodosa		+	
Convolvulus althaeoides	Convolvulaceae	+	+
Convolvulus elegantissimus		+	+
Fumaria officinalis	Papaveraceae	+	+
Papaver nigrotinctum		+	+
Papaver rhoeas		+	+
Agrostemma githago	Caryophylaceae	+	+
Stellaria media		+	+
Silene cretica		+	+
Amaranthus deflexus	Amaranthaceae	+	+
Anacamptis pyramidalis	Orchidaceae	+	+
Neottia nidus-avis		+	
Anagallis arvensis	Primulaceae	+	+
Asterolinon linum-stellatum		+	+
Cyclamen graecum		+	+
Bellardia trixago	Orobanchaceae	+	+
Verbascum undulatum		+	
Bituminaria bituminosa	Fabaceae	+	+
Onobrychis caput-galli		+	+
Scorpiurus muricatus		+	+
Campanula spatulata	Campanulaceae	+	+
Erodium cicutarium	Geraniaceae	+	+
Geranium robertianum		+	+
Geranium tuberosum		+	
Lilium candidum	Liliaceae		
Muscari comosum	Hyacinthaceae	+	+
Narcissus tazetta	Amaryllidaceae		
Tuberaria guttata	Cistaceae	+	+
Lamium amplexicaule	Lamiaceae	+	+
Phlomis fruticosa		+	
Salvia verbenaca		+	+
Salvia viridis		+	+
Micromeria nervosa		+	
Carex flacca	Cyperaceae	+	
Echium plantagineum	Boraginaceae	+	+
Knautia integrifolia	Dipsacaceae	+	+
Scabiosa stellata		+	
Euphorbia helioscopia	Euphorbiaceae	+	+
Mercurialis annua		+	+
Chenopodium album	Chenopodiaceae	+	+
Galium aparine	Rubiaceae	+	+
Gladiolus italicus	Iridaceae	+	+
Plantago major	Plantaginaceae		+
Geum coccineum	Rosaceae	+	
Tribulus terrestris	Zygophyllaceae	+	
Urtica dioica	Urticaceae	+	+

Table A3. Woody plant species recorded in organic and conventional olive groves. Species nomenclature according to Dimopoulos et al. (2013, 2016) [37,38].

Species	Family	Organic Olive Groves	Conventional Olive Groves
Arbutus andrachne	Ericaceae		
Arbutus unedo	Ericaceae		
Crataegus monogyna	Rosaceae	+	+
Calicotome villosa	Fabaceae		
Cercis siliquastrum	Caesalpiniaceae	+	+
Cistus creticus	Cistaceae		
Erica manipuliflora	Ericaceae	+	+
Ficus carica	Moraceae		
Fumana thymifolia	Cistaceae		
Juniperus oxycedrus	Cupressaceae		+
Juniperus phoenicea	Cupressaceae	+	+
Myrtus communis	Myrtaceae		
Olea europaea	Oleaceae	+	+
Olea. europaea var. sylvestris	Oleaceae	+	+
Paliurus spina-christi	Rhamnaceae	+	+
Phlomis fruticosa	Lamiaceae	+	+
Pistacia lentiscus	Anacardiaceae	+	+
Pistacia terebinthus	Anacardiaceae		
Pyrus spinosa	Rosaceae	+	+
Quercus coccifera	Fagaceae	+	+
Quercus pubescens	Fagaceae		
Rhamnusalaternus	Rhamnaceae		
Rubus fruticosus	Rosaceae	+	+
Satureja thymbra	Lamiaceae	+	
Smilax aspera	Smilacaceae	+	
Spartium junceum	Fabaceae		+
Ulmus glabra	Ulmaceae	+	
Vitex agnus-castus	Verbenaceae	+	+

Table A4. Isopod species recorded in organic and conventional olive groves. Species nomenclature based on Schmalfuss (2003; 2008) [90,91].

Species	Family	Organic Olive Groves	Conventional Olive Groves
Armadillidium tuberculatum	Armadillidiidae	+	+
Armadillidium vulgare	Armadillidiidae	+	+
Armadillo officinalis	Armadillidae	+	+
Leptotrichus naupliensis	Porcellionidae	+	
Porcellio laevis	Porcellionidae	+	+
Porcellio obsoletus	Porcellionidae		+
Porcellionides pruinosus	Porcellionidae	+	+

Table A5. Earthworms species recorded in organic and conventional olive groves. Species nomenclature based on Graf (1955); Zicsi (1991); Christian and Ziscs (1999) [92–94].

Species	Family	Organic Olive Groves	Conventional Olive Groves
Aporrectodea caliginosa	Lumbricidae	+	+
Aporrectodea trapezoides	Lumbricidae	+	
Dendrobaena byblica	Lumbricidae	+	+
Dendrobaena cognettii	Lumbricidae	+	
Dendrobaena veneta	Lumbricidae	+	
Microscolex dubius	Megascolecidae	+	+
Microscolex phosphoreus	Megascolecidae	+	
Octodrilus complanatus	Lumbricidae	+	+
Octodrilus croaticus	Lumbricidae	+	+

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