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Family Farming Plays an Essential Role in Preserving Soil Functionality: A Study on Active Managed and Abandoned Traditional Tree Crop-Based Systems

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Abstract: In traditional agricultural areas, where traditional crops (TCs) are cultivated, small farms are still highly represented. Located prevalently in marginal and sensitive areas, agricultural areas have undergone deep transformation. Smallholders have maintained the traditional asset of cultivation (extensive and low input requirement management) only to some extent. In some cases they have adapted traditional orchards into more intensive planting systems. Frequently, they have abandoned agriculture. The land use and management influence soil functions, i.e., the capability of a specific soil to provide key functions in terrestrial ecosystems. In order to assess whether small farms are environmentally sustainable, we used a set of soil quality indicators in three traditional tree crops in the Latium region (central Italy), like hazelnut, grapevine, and Citrus. The soil parameters, chemical, biological, and biochemical, were quantified under three different management models: extensive cultivation, intensive cultivation, and abandonment. The selected set of indicators proved to be able to discriminate adequately between the management models and to be suitable for the soil health assessment. Results proved that hazelnut orchards stored more organic C, independently from farming management, while vineyard showed the lower total organic carbon (TOC). The microbial carbon vs. organic carbon ratio (Cmic-to Corg ratio) was higher for vineyards and Citrus groves, denoting a more active degradation of soil organic matter. Soil enzymes (ESs) involved in C cycle were variable along the different treatments and mainly influenced by the C inputs to soil and soil cover, whereas those involved in N, P, and S cycles were higher in abandoned and extensive TCs. Overall, extensive cultivation performed better in terms of soil quality than intensive or abandonment. This study suggests that a transition to an agriculture based on agroecological principles and toward extensification would provide significant soil-based environmental benefits in marginal sensitive areas.

Keywords: abandoned land; traditional agricultural landscape; agro-forestry; *Citrus x sinensis*; *Corylus avellana*; intensification; extensification; *Vitis vinifera*

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1. Introduction

Life's quality on the earth depends on healthy soils that are recognized to support food production, to provide ecosystem services (provisioning, regulating, supporting, and cultural services), among which are biodiversity and biogeochemical cycles [1–3]. Soil quality depends on land use and cultivated surfaces may contribute to soil functionality preservation [4]. Nevertheless between 50% and 70% of agricultural land has been lost and/or its fertility has been reduced [5] due to climate-driven changes that reduce crops' productivity or human-driven changes, such as urbanization and agricultural abandonment in marginal areas. On the other hand, there is an urgent need to drive agriculture toward the sustainable use of environmental resources by assuring at the same time increase in crop productivity, leading to increasing agricultural output by capitalizing on ecological processes in agro-ecosystems [6,7], this objective can be achieved by including "ecosystem services" [8], "sustainable intensification" [9], and "climate-smart agriculture" [10] in farm management. Many agro-ecosystem management models and practices promote the sustainable management of soils, that preserve soil health based on functions like conservation agriculture, integrated pest management, organic farming, grassing, polycultures, agroforestry systems [11–13]. Traditional agriculture, mainly operated by smallholders and small family farmers, represents one of the most effective land use for natural resource sustainable management, integrated ecosystem services provision, including the preservation of local germplasm at the base of traditional products and sustainable agricultural practices [14–17], land defense against soil sealing mainly in peri-urban areas as well as multifunctional landscapes [18–22]. Traditional agricultural land uses, like poly-cultural tree crop based agro-ecosystems, have been proved to counteract soil degradation caused by wildfires, landslides, and uncontrolled re-naturalization process mainly in steep areas, widely spread all over the Mediterranean [23,24]. Familiar agriculture is gaining importance also for its cultural and social function and in general for agriculture resilience in many extra-UE countries, but little information are available for this role in the Mediterranean basin [14,25,26].

Soil health represents the "continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal, and human health" [27] being different from the quality of soil, that is represented by a set of physical, chemical, and biological properties that together can provide a suitable or unsuitable medium for plant growth and biological activity [28,29]. The assessment of soil health, or rather how well soil performs all its functions now and how those functions are being preserved for future use, requires a set of indicators at local level, able to represent the changes of soil functions in response to changes in the agrosystem. Indicators with a rapid response to natural or anthropogenic drivers may be considered more suitable indicators of soil health evolution in the short term. In fact, the physical (e.g., soil texture, aggregation, moisture, porosity, bulk density) and the chemical parameters (e.g., total organic carbon (TOC) and total nitrogen (TN), phosphorus (P), potassium (K), cation exchange capacity), are common and widely employed indicators of soil quality. However, most of them generally have slow response to changing factors, whereas the biological parameters, such as the soil microbial biomass (Cmic), the microbial community size (as dsDNA), and the soil enzymes, represent key indicators for soil ecosystems dynamics, allowing for timely improvement of soil health and plant productivity through the adoption of mitigation strategies, when necessary [30]. Soil microbial biomass (Cmic) is among the most labile pool of organic matter and an important reservoir of plant nutrients with a crucial role in organic matter transformation, biochemical cycling, soil structure stabilization [31], and hence is an early indicator of changes resulting from agronomic practices [32]. Cmic generally represents 1–4% of total organic carbon (TOC), both Cmic and the Cmic with respect to total organic carbon ratio (Cmic-to Corg ratio) are considered to be useful parameters to monitor soil organic matter changes in response to agricultural management practices adopted at farm level [33,34]. Soil enzymes (SEs), showing a high sensitivity to environmental stress and responding rapidly to changes in land management [35], can be considered bioindicators of soil ecosystems status [36] and enable to detect changes in soil health in response to land use and land cover changes, and land abandonment [37]. In addition, SEs are useful soil quality indicators because modification on their status might affect soil microbial community, due to their role in the geo-biochemical cycles. They are also indicative of biological equilibrium, soil fertility or soil pollution [38,39]. The assessment of soil health in smallholder agricultural systems that are endangered by poor resilience to climate, social, and economic changes, is crucial to understanding the role of familiar agriculture approaches on ecosystem restoration and natural resource management in order to provide information on biochemical effects on soil health and its roles to produce environmental externalities and to increase the resilience of agriculture to global climate changes.

In this framework, we focused on soil-based ecosystem services provided by traditional Mediterranean tree-crops in family farming contest and compared the quantitative and qualitative impact on soil health under different management status and models. In particular the study aims to investigate at family farm scale the soil health through chemical, biochemical, and enzymatic characterization as indicators of soil functionality under different management status, like active intensive or extensive cultivation versus abandonment and for three traditional Mediterranean crops: *Vitis vinifera* L., *Corylus avellana*, and *Citrus x sinensis.*

2. Materials and Methods

2.1. Study Area and Field Sites

The study was carried out in areas of traditional agriculture of the Latium region (central Italy), a territory characterized by Mediterranean climate (Csa)—according to the modified Köppen-Geiger scheme [40]. The morphology and physiography of this Mediterranean region is highly complex, the elevation varies from 0 to nearly 2200 m a.s.l., with coastal planes as well as coastal mountains, inner hills, and mountains. Due to these high physiographic variability, Latium region is divided into four main sub-regions: coastal areas, inland plains, mountains of the Latium Pre-Apennines and Apennine area, that represent also different climatic zones, from dry (coastal areas) to humid (Apennine zone) [41]. The study areas are located in three geographical sites: inner hills of Bolsena lake (northern Latium), Cimini hills (northern Latium) and coastal plain of Terracina and Fondi (southern Latium) (Figure 1). In terms of suitability to agriculture, following the regional Soil Classification for agricultural suitability, the soil of the study cases belong to the 2nd and 3rd agricultural suitability class, i.e., soils with limitation to agriculture (in terms of possible crops and necessity of conservation practices) ranging from low to medium, for the first study area and the other two, respectively [42].

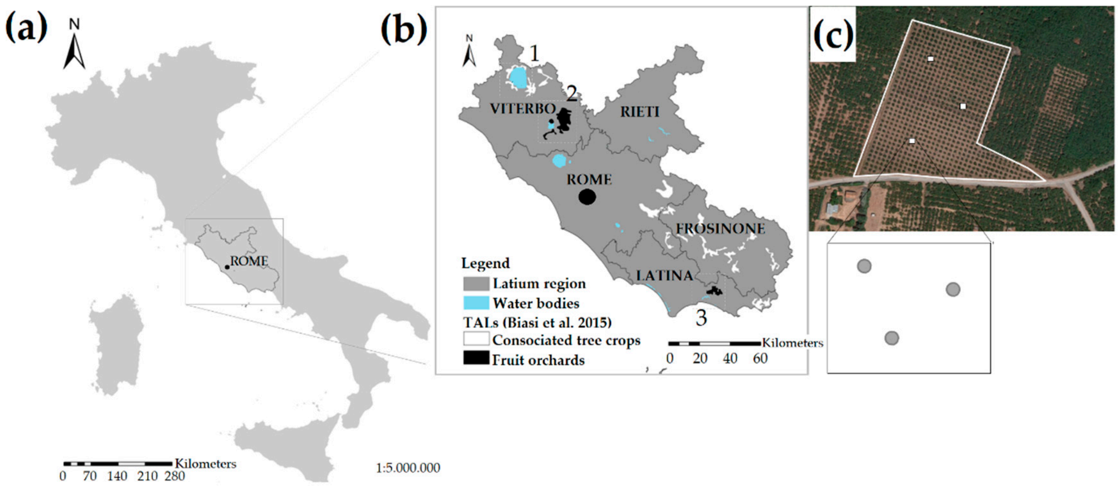

Figure 1. Delimitation of the Latium region (**a**) and three selected traditional agricultural areas (TALs) (**b**): vineyards, hills of Bolsena lake (1); fruit orchards- hazelnut, hills of Cimini district (2); citrus groves, coastal plain of Terracina (3). Design of soil benchmarks 1 m^2 sampling (**c**) and soil subsampling design adopted in each study site for soil analysis.

Three study sites were considered in the study, each characterized by traditional crops (TCs). The three traditional agricultural areas (TALs) were identified according to Biasi et al., 2015 [18] (Figure 1b):

- *Vitis vinifera* L.: vineyards placed on hills of Bolsena lake (northern Latium);
- *Corylus avellana*: hazelnut orchards, located in the agricultural district of Cimini hills (northern Latium);

- *Citrus x sinensis*: Citrus groves in the coastal plain of Terracina and Fondi (southern Latium).

Citrus groves (C) are located on dry coastal areas of southern Latium region [20] while vineyards (V) on volcanic lapillus soil, a very loose soil [43] and in warm temperate climate [15]. Hazelnuts groves (H) are in an inner hilly area, where 70% of the Italian hazelnut cultivation is concentrated [44–46]. For each traditional crop (TCs), three management models were considered, namely no management (abandoned former cropping systems), traditional (extensive and consociated), and modern (intensive) (Figure 2).

The main distinctive traits of each tree cropping model are:

1. Abandoned crops (A): natural recolonization of former agro-systems. The status of abandonment was attributed to "agricultural land on which it has not been exercised agricultural activity for at least ten years" (Italian Decree-Law 20 June2017, n. 91, art.3);
2. Extensive cultivation (E): mixed cropping systems (mainly consociation with trees belonging to different species and/or genotypes), small surface, low planting density, low level of external inputs and mechanization, low yield;
3. Intensive cultivation (I): large surface, monocultural systems, high density planting, high level of external inputs, mechanization, high yield.

All the cropping systems were conducted by smallholder farmers and represented different typology of familiar agriculture. The characteristics of each studied agrosystem is reported in Table 1.

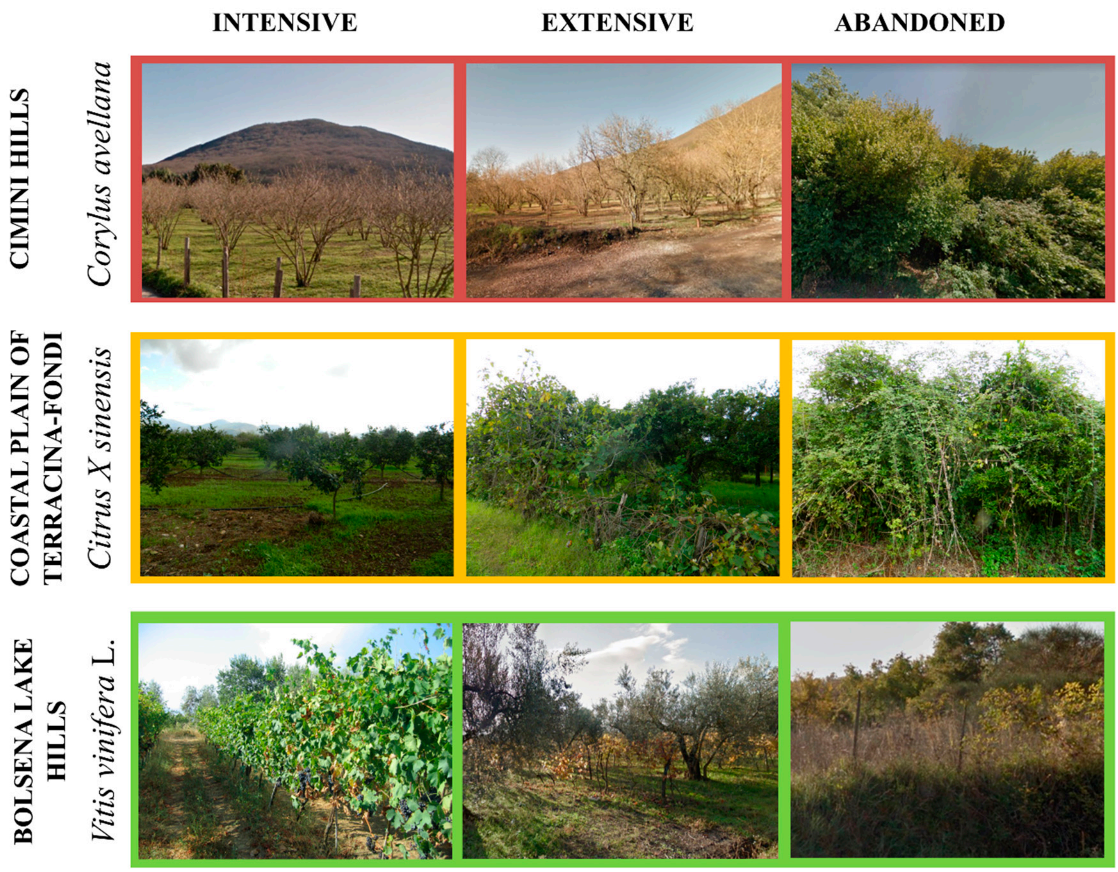

Figure 2. Traditional crops (TCs) (*Corylus avellana*, *Citrus x sinensis* and *Vitis vinifera* L.) selected in traditional agricultural areas (TALs: Cimini hills, Coastal plan of Terracina–Fondi, Bolsena lake hills) under three different farming systems: abandoned (A), extensive (E), and intensive (I).

Table 1. Geolocalization (geographic coordinates), description of the main constitutive traits and floor management practices in the traditional cropping systems (TCs) [18] of Latium region (Italy) under different farming models: abandoned (A); extensive (E); intensive (I).

TALs	TCs	Coordinate	Farming Systems	Constitutive Traits	Soil and Crops Management Practices
CIMINI HILLS	*Corylus avellana*	42°18′23″ N 12°12′12″ E	A	Planted in early 1970, and completely abandoned since 1993. Surface of 0.49 ha. Local landrace associated to shrubs, herbs, and weeds that colonize the space between trees and rows. Hazelnut trees, previously grown as multi stemmed bushes, are now as big shrubs.	Spontaneous and permanent grassing. No soil tillage management. No herbicide treatments. No mechanical weed control.
		42°21′10″ N 12°10′26″ E	E	Planted in early 1970. Surface of 0.60 ha. The orchard is grown as multi stemmed bushes with planting distances 7 m × 5 m (between and within the row, respectively). The bushes are periodically renewed by pruning old and bad oriented stems in the bushes.	Spontaneous and temporary grassing. No soil tillage management. Herbicide treatments and mechanical weed control (three times per year).
		42°21′09″ N 12°09′53″ E	I	Planted in early 2001. Surface of 1.90 ha. The orchard is grown as multi stemmed bushes and with planting distances 5 m × 4 m (between and within the row, respectively)	Spontaneous and temporary grassing. No soil tillage management. Herbicide treatments and mechanical weed control (three times per year).
COASTAL PLAIN OF TERRACINA-FONDI	*Citrus x sinensis*	41°22′25.96″ N 13°23′44.47″ E	A	Planted in early 1960, and abandoned since 2007. Surface of 0.55 ha. Local landrace associated to shrubs, herbs, and weeds that colonized the space between trees and rows. Consociated with apple, medlar, fig, mulberry, pomegranate, and cherry trees.	Spontaneous and permanent grassing. No soil tillage management. No herbicide treatments. No mechanical weed control.
		41°21′48.26″ N 13°23′47.82″ E	E	Planted in 1987. Surface of 0.33 ha. Orchard characterized by local landraces consociated with grape, pomegranate, medlar and prickly pea, and annual crops.	Spontaneous and temporary grassing. No soil tillage. No herbicide treatments. Mechanical weed control (Twice per year)
		41°20′55.62″ N 13°21′26.92″ E	I	Intensive orchards planted in 1997. Surface of 0.42 ha, high tree density (>250 plants per hectare), international Citrus varieties.	Spontaneous and temporary grassing. Shallow tillage. No herbicide treatments. Mechanical weed control (Twice per year)
BOLSENA LAKE HILLS	*Vitis vinifera* L.	42°38′17.6″ N 11°51′59.2″ E	A	Planted in early 1970 and abandoned in 2008. Surface of 0.25 ha. Local landrace associated to shrubs, herbs, and weeds that colonized the space between trees and rows. Consociated with olive, chestnut, Figure trees	Spontaneous and permanent grassing. No soil tillage management. No herbicide treatments. No mechanical weed control.
		42°38′32.13″ N 11°53′7.38″ E	E	Planted in 1970. Surface of 0.33 ha. Orchard characterized by local landraces consociated with olive trees and local annual crops.	Spontaneous and temporary grassing. No soil tillage. No herbicide treatments. Mechanical weed control (Three times per year)
		42°38′12.02″ N 11°52′36.58″ E	I	Intensive orchards planted in 1980, Surface of 0.21 ha, high vine density (4000 vines per hectares), local landrace and national/international varieties.	Spontaneous and temporary grassing, shallow tillage (15-cm depth) carried out two times per year. Herbicide treatments and mechanical weed control (three times per year)

2.2. Soil Sampling Design and Analyses

In autumn the bulk soil samples were collected in the three representative agro-ecosystems for each TCs. Three soil benchmarks sampling of defined surface (1 m^2) for each agro-ecosystems were randomly identified (Figure 1c) and for each of them three sub-samples were taken from 0–20 cm topsoil using a gouge auger (3.5 cm diameter). The nine sub-samples per agro-ecosystems were sampled on the same day. All visible roots and coarse fragments (>2 mm) were removed, and the soil eas air dried up to constant weight. Soil samples were then sieved with 2-mm sieves and stored at room temperature until they were analyzed. Each site was characterized by 23 soil bio-chemical parameters, as shown in Supplementary Materials.

Soil organic carbon (TOC) content was assessed by means of a LECO RC612 Carbon Analyzer (LECO Corp. St. Joseph, MI, USA), according to Brunori et al., 2016 [47]. The activities of the ESs were determined on soil extracts applying an extraction/desorption procedure [48], and using fluorescent analogues of each enzyme's substrate on microplates. Extracts were obtained with the same procedure as for dsDNA, except for the desorbing buffer (4% lysozyme). After centrifugation, supernatants containing desorbed enzymes were dispensed in 384-well microplates with appropriate buffer to determine EAs using fluorescent 4-methyl-umbelliferyl- and 7-amino-4-methyl-coumarine-based substrates. In this study we measured the level of 17 SEs linked with C, N, P, and S cycles, namely acetate-esterase (ester-ac), acid phosphomonoesterase (acP), α- and β-glucosidase (alfaG and betaG), alkaline phosphomonoesterase (alkP), arylsulfatase (aryS), cellulase (cell), chitinase (chit), glucuronidase (uroni), inositol-phosphatase (inosit), leucine-aminopeptidase (leu), nonanoate_esterase (ester-nona), palmitate-esterase (ester-palm), phosphodiesterase (bisP), pirophosphate-phosphodiesterase (piroP), tripsin- and papain-like protease (trip), xilosidase (xil). Total N (TN) and soluble P (Psol) were extracted using 5 g (dry basis) of moist soil and 20 mL of 0.5 M potassium sulfate for 30 min. Extracts were filtrated using glass fiber filters (Whatman GF-F). N content in the extracts was determined by a Shimadzu TOC-V CNS analyzer equipped with Nitrogen module. P was determined using malachite green method [49]. Microbial biomass carbon (Cmic), expressed in mg C kg^{-1} soil, was determined with the chloroform fumigation-extraction method [50], on air-dried soils, pre-conditioned by a 10-d incubation in open glass jars at field capacity and 30 °C [51].

2.3. Data Analysis

This study was conducted with a completely randomized design. The effects of different TCs and farming intensity on chemical, and microbial characteristics of soil were analyzed by ANOVA, and mean separations were computed using Duncan's multiple range test. Grubbs procedure has been adopted to detect outliers data before proceeding to analyze the data for regression analysis between TOC and TN content, and also between TOC contents and ratio of microbial biomass carbon (Cmic) to total organic carbon (Cmic-to Corg ratio) for tested TCs under different farming management systems, abandoned (A); extensive (E); intensive (I).

For relationships among these soil components, linear, power, and quadratic functions were tested, and the lowest p value and/or highest R^2 were used to describe the relationship. Soil chemical and microbial data were subjected to a two-way analysis of variance to compare the mean differences between 3 TCs and 3 types of farming systems (A, E and I) selected as independent variables (factors), with the primary purpose to understand if there was an interaction between the two factors on the dependent variables. F-test provides the p-value and the critical values for alpha level of 0.05 (*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, ns: not significant.)

Principal components analysis (PCA) was performed to investigate how all soil variables (chemical and enzymatic activity) fitted to factors, with the following steps. First, multicollinearity test has been carried out to verify the high intercorrelations or inter-associations among the variables and to identify disturbance in the data. Second, Kaiser-Meyer-Olkin (KMO) was measured to assess the adequacy for each variable in the model and for the complete model, to have information about their suitability for multivariate analysis. Hence variables with communality values <0.5 (Barlett's test) were removed. Finally, we run PCA applying a standardization using Pearson's coefficient method. The selection of PC was done following the latent root criterion (eigenvalues >1.0).

Bivariate analysis was also performed with Pearson's linear correlation between soil variables. Discriminant analysis (DA) is used to analyze the differences between two or more groups of multivariate data using one or more discriminant functions to maximally separate the identified groups. Therefore, DA was employed to find the difference between the land uses along with the soil variables. All the data were analyzed with XLStat version 2014.6.01 (Addinsoft, New York, NY, USA).

3. Results

3.1. Soil Chemical and Biological Properties

All the considered crops in each farming model (A, E, and I) were tested for the soil functionality. The whole investigation was focused on the soil quality traits, as listed in Supplementary Materials. Soil chemical properties, namely TOC and TN content, TOC/TN ratio, Cmin concentrations, and the Cmic-to Corg ratio are summarized in Table 2.

Table 2. Soil chemical parameters (mean values) for TOC (%) TN (g·kg^{-1}), TOC/TN-ratios (C/N), organic carbon of microbial biomass (Cmic (µg·g^{-1} soil DW) and ratio between Cmin and total organic carbon (Cmic- to Corg ratio) in topsoil samples (0–20 cm depth) of traditional cropping systems (TCs) of Latium region (Italy) under different farming models: abandoned (A); extensive cultivation (E); intensive cultivation (I). Different letters (*a*,*b*) in the same columns indicate significant differences between means ($p < 0.05$).

TCs	Farming Systems	TOC (%)		TN (g·kg^{-1})		C/N		Cmic (µg·g^{-1} Soil DW)		Cmic- to Corg Ratio (%)	
Corylus avellana	A	2.72	*b*	0.21	*a*	13.55	*b*	25.99	*a*	0.955	*a*
	E	3.66	*a*	0.25	*a*	14.93	*a*	11.24	*b*	0.307	*b*
	I	2.34	*b*	0.22	*a*	10.53	*b*	19.40	*b*	0.829	*a*
Citrus x sinensis	A	2.69	*a*	0.27	*a*	10.19	*a*	38.31	*a*	1.424	*a*
	E	2.80	*a*	0.26	*a*	10.77	*a*	41.99	*a*	1.499	*a*
	I	1.91	*b*	0.13	*b*	14.73	*b*	20.38	*b*	1.067	*b*
Vitis vinifera L.	A	1.65	*a*	0.14	*a*	12.75	*b*	24.20	*b*	1.467	*b*
	E	1.72	*a*	0.12	*a*	14.71	*a*	35.91	*a*	2.088	*a*
	I	1.17	*b*	0.08	*b*	15.58	*a*	19.64	*b*	1.679	*b*

With regard to TOC the content was as follows: V_I < V_A < V_E < C_I < H_I < C_A < H_A < C_E < H_E. As average, hazelnut groves (H) showed significant higher TOC values than vineyards (V) (+46%) and citrus groves (C) (+15%) (Figure 3). As for the farming models, the extensive (E) farming showed the highest TOC content with respect to both intensive management (+33%) and crop land abandonment (+14%). In citrus groves and vineyards TOC contents varied significantly among A and E with respect to I. Vineyards and citrus groves under intensive management showed the lowest TOC level compared to other farming systems. TN concentration in topsoil (0–20 cm depth) for TCs ranged from 0.08–0.27 (%). Significant differences have been found for TN content only among vineyards and citrus groves, where intensive farming systems (I) showed the lower topsoil TN (0.08 and 0.13 respectively) than in the other ones.

The C/N ratio ranged between 10.2 and 15.6 depending on the TCs and farming systems, with significant differences (Table 2). C/N highest values were found in intensive vineyards (V_I) and citrus groves (C_I) (15.6 and 14.7 respectively) and in extensive hazelnut orchards (H_E) (14.9). A linear relation ($R^2 = 0.71$) between TOC and TN was found (Figure 4). Data were clustered in two groups in relation to TOC content below and above the threshold of 2% TOC. Vineyards under all farming systems and the intensive citrus groves (C_I) were located below this threshold, that means in a poor soil fertility condition, whereas hazelnut (all farming systems) and in extensive and abandoned citrus groves (C_E and C_A) lied above 2%.

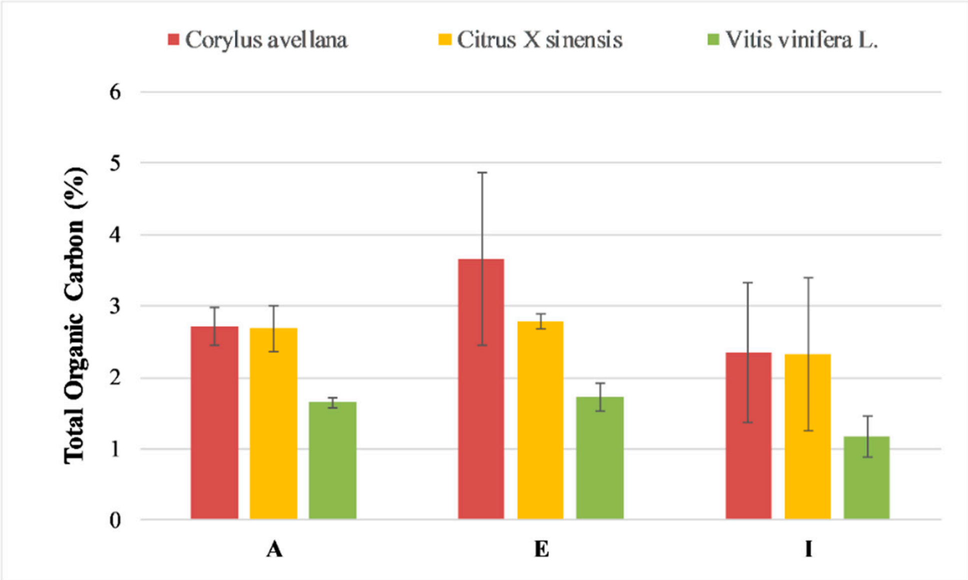

Figure 3. Topsoil (0–20 cm depth) total organic carbon (TOC) contents (%) for Traditional Cropping systems (TCs) studied under different farming models: abandoned (A); extensive (E); intensive (I).

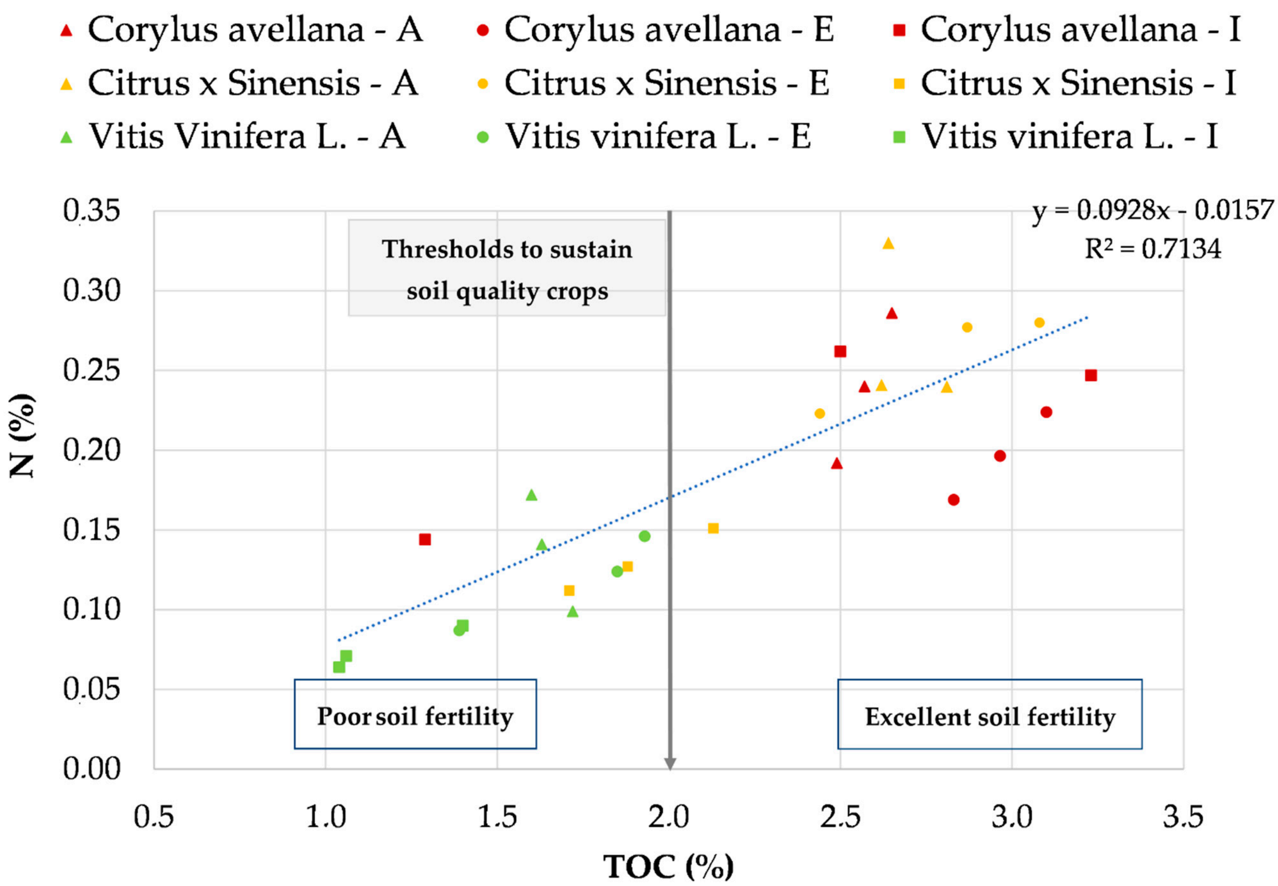

Figure 4. Linear correlation (dashed line) for the topsoil Total Organic Carbon (TOC) contents (%) and Total Nitrogen (TN) content g·kg^{-1}, for Traditional Cropping systems (TCs) studied under different farming model: abandoned (A); extensive (E); intensive (I).

Regarding Cmic and Cmic-to Corg ratio (Table 2) significant differences have been shown among all farming systems for TCs. Generally, citrus groves and vineyards showed higher values of Cmic to Corg ratio than hazelnuts agrosystems. In particular, V_E exhibits the higher Cmic close to two-fold of V_I, and the highest Cmic-to Corg ratio. In hazelnut groves, where TOC was higher than 2% in all farming systems, Cmic and Cmic-to Corg ratio showed lower values in extensive (H_E) condition, due to highest content in TOC.

Grubbs statistics did not detect outliers for TOC, TN, TOC/TN, Cmic and Cmic-to Corg ratio. The factorial analysis of variance performed on a 3 × 3 factorial design (H,C,V) x (A, E, I) showed that TCs and farming management systems affected significantly all the tested soil chemical parameters and microbial biomass content. The Cmic-to Corg ratio was the only variable significantly affected by the interaction of TCs x farming system i ($p < 0.001$) (Table 3).

Table 3. Two-way ANOVA factorial analysis (3 × 3) for 3 TCs (hazelnut orchard, citrus grove and vineyard) and 3 types of farming systems (A, E, and I) and their interaction. Significant differences *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, ns: not significant. [Total Organic Carbon (TOC), Total Nitrogen (TN) content, TOC to TN ratio, ratio of microbial biomass carbon (Cmic) to total organic carbon (Cmic-to Corg ratio)].

EFFECT	TOC (%)	TN (g·kg^{-1})	TOC/TN	Cmic-to Corg Ratio
TCs	**	**	*	**
Farming system	*	*	*ns*	*ns*
TCs x Farming system	*ns*	*ns*	*ns*	**

3.2. Soil Enzymes

Soil enzymes content differed consistently among crops and farming systems (Table 4), ranging from very low values in soil of citrus groves, medium for vineyards, and medium-high value for hazelnut orchards. One-way ANOVA applied to these data showed significant data variability within each TCs) and among farming management systems (A, E, I). In detail, AryS was higher (34.9 nmol 4-MUF g^{-1} h^{-1}) in abandoned hazelnut than the average of the other TCs and management systems (4.89 nmol 4-MUF g^{-1} h^{-1}). In general, citrus groves for all farming systems reached the lower activities for enzyme involved in the N cycle (chit, leu, and tryp), while H_A and V_E systems showed higher values than the other crops and farming system combination. Citrus orchards exhibited lower activities in the ESs involved in the carbon cycle (α-G, β-G, Cell, Xil, and Uro) and on the organic matter decomposition, that were lower in H_I and V_E systems. The other ESs of the carbon cycle, mostly involved in the humification process such as acetate-esterase, nonanoate-esterase showed greater activity for V_E, C_A, H_I, and H_A, while palmitate-esterase did not show significant difference among all tested combinations. For the ESs involved in the P cycle, namely acid phosphomonoesterase, phosphodiesterase, pirophosphate-phosphodiesterase, inositol-phosphatase, and alkaline phosphomonoesterase the highest content was showed in hazelnut for all farming systems and in C_A, V_E, and V_A.

Table 4. Enzymatic activities (mean values) (nmol 4-MUF g-1 h-1) in tested TCs (hazelnut orchards—*Corylus avellane*; citrus groves—*Citrus x sinensis*, and vineyards—*Vitis vinifera* L.) as related to different farming management system (A: abandoned; E: extensive and I: intensive). Different letters *(a–c)* in the same column indicate statistical differences between treatments (Duncan's multiple range test, p = 0.05). Columns' color identifies enzymes for specific biogeochemical cycles: sulfur, nitrogen, carbon, and phosphorus cycle.

		Sulfur Cycle	**Nitrogen Cycle**			**Carbon Cycle**								**Phosphorus Cycle**				
TCs	**Farming Systems**	**aryS**	**chit**	**leu**	**trip**	**α-G**	**β-G**	**cell**	**xil**	**uro**	**ester-AC**	**Ester-nona**	**Ester-palm**	**acP**	**bisP**	**piroP**	**inositP**	**alkP**
Corylus avellana	A	34.99 *a*	4.17 *a*	34.30 *a*	2.01 *a*	0.57 *ab*	6.45 *b*	0.59 *ab*	1.25 *b*	0.58 *b*	1360.67 *a*	120.04 *a*	0.64 *a*	68.81 *a*	37.71 *a*	19.56 *a*	3.57 *a*	139.29 *a*
	E	5.79 *b*	5.15 *a*	12.28 *c*	0.62 *b*	0.24 *b*	6.82 *b*	0.34 *b*	1.69 *b*	0.43 *b*	717.23 *b*	57.95 *c*	0.56 *a*	30.79 *c*	5.92 *b*	1.63 *b*	0.77 *b*	22.76 *b*
	I	7.07 *b*	6.67 *a*	22.93 *b*	0.97 *b*	0.79 *a*	14.14 *a*	0.81 *a*	4.10 *a*	1.10 *a*	1046.20 *ab*	87.90 *b*	0.97 *a*	54.65 *b*	7.84 *b*	3.34 *b*	1.28 *b*	52.58 *b*
Citrus x sinensis	A	5.80 *a*	2.91 *a*	17.51 *a*	1.56 *a*	0.34 *a*	5.41 *a*	0.36 *a*	0.95 *a*	0.52 *a*	620.78 *a*	106.67 *a*	1.98 *a*	27.26 *a*	30.88 *a*	8.75 *a*	1.69 *a*	130.07 *a*
	E	3.04 *b*	2.63 *a*	15.39 *a*	1.24 *b*	0.00 *b*	4.59 *ab*	0.26 *a*	0.91 *a*	0.42 *ab*	437.17 *b*	85.94 *a*	2.28 *a*	18.60 *ab*	23.65 *a*	6.58 *a*	1.47 *a*	90.36 *ab*
	I	0.80 *c*	1.58 *a*	6.23 *b*	0.51 *c*	0.08 *b*	3.09 *b*	0.17 *a*	0.64 *a*	0.26 *b*	233.61 *c*	36.22 *b*	1.12 *a*	14.42 *b*	4.31 *b*	1.51 *b*	0.62 *b*	22.95 *b*
Vitisvinifera L.	A	4.64 *b*	5.54 *a*	21.58 *b*	1.36 *b*	0.55 *ab*	5.91 *b*	0.57 *ab*	1.48 *b*	1.37 *a*	613.81 *b*	66.25 *b*	0.92 *a*	28.95 *b*	21.88 *a*	7.65 *a*	1.51 *a*	91.26 *a*
	E	7.92 *a*	6.28 *a*	45.48 *a*	3.60 *a*	0.68 *a*	9.07 *a*	0.71 *a*	2.46 *a*	0.90 *a*	983.97 *a*	188.38 *a*	1.82 *a*	37.42 *a*	23.36 *a*	9.70 *a*	1.39 *a*	115.71 *a*
	I	4.06 *b*	3.97 *a*	20.67 *b*	2.16 *b*	0.39 *b*	5.08 *b*	0.41 *b*	1.40 *b*	0.94 *a*	623.23 *b*	98.21 *ab*	1.71 *a*	21.21 *c*	12.31 *a*	5.01 *a*	1.16 *a*	66.64 *a*

3.3. Multivariate Statistical Analysis

All data have been subjected to correlation analysis (Figure 5). Kaiser-Meyer-Olkin's (KMO) and the Bartlett's test of sphericity were carried out to test if the data were suited for multivariate statistical analysis (MA). The measure of sampling adequacy by KMO (0.4) indicates that the sample size was not adequate to MA. By excluding lower KMO values (TN, Cmic, C/N) a new dataset with KMO value of 0.6 was obtained, indicating the goodness of the set of variables to perform MA. However, since Bartlett's test revealed high similarity and high correlation among some enzyme's activities (cell, xil, piroP, inositP, alkP (Figure 5), also these variables were excluded by MA to avoid redundant data. Finally, we run a principal component analysis (PCA) to describe the variability among observed and correlated variables in order to find out the factors (F1 and F2) that create a commonality. The first two factors (F) explained about 63% of the total variation (measured by the inertia), sufficient for our exploratory purposes. The results of principal component analysis (PCA)—as method for factor extraction (F1 and F2)—and agglomerative hierarchical clustering (AHC) are shown in Figure 6.

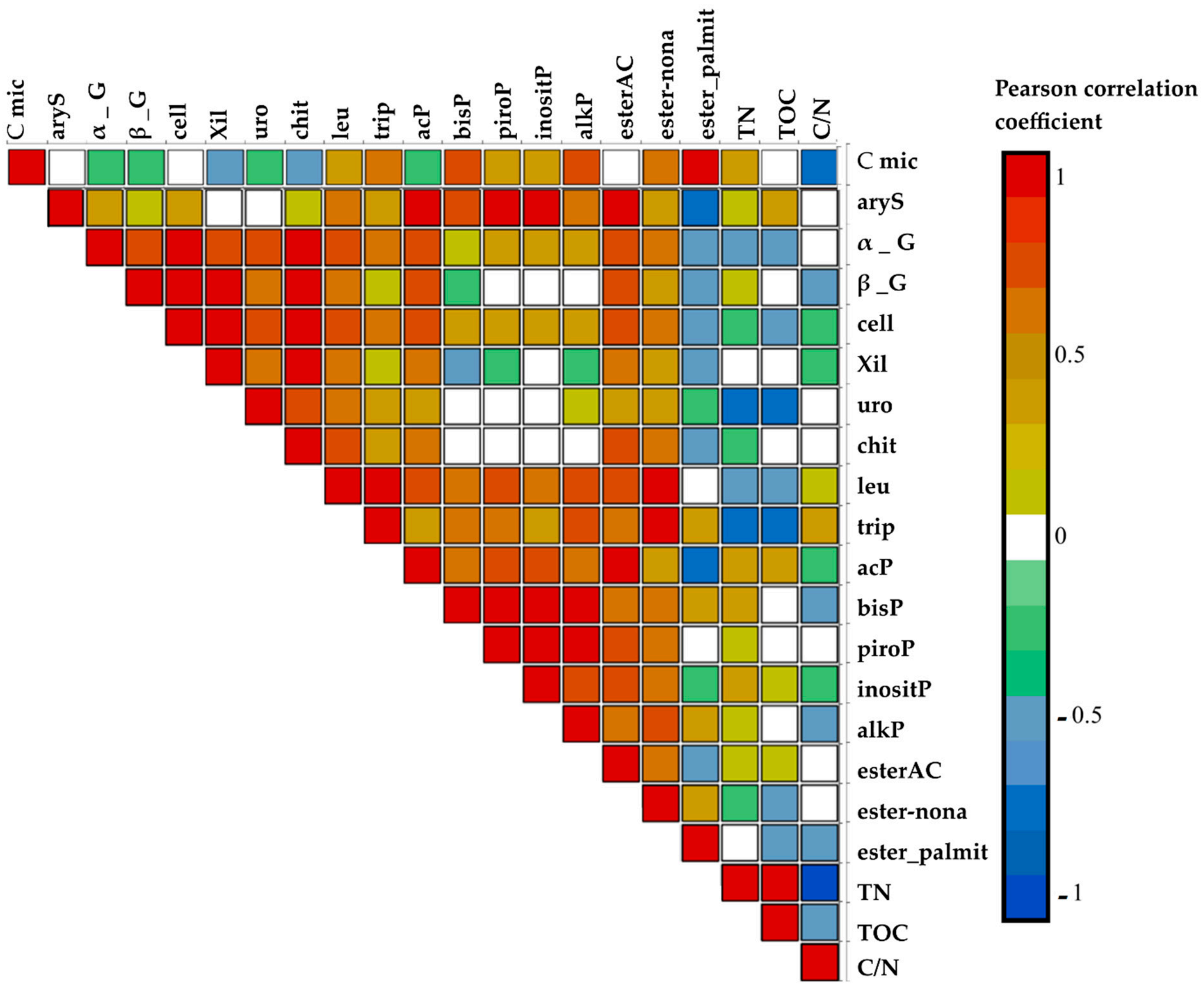

Figure 5. Correlation maps (Pearson correlation coefficient) among chemical and biological soil indicators.

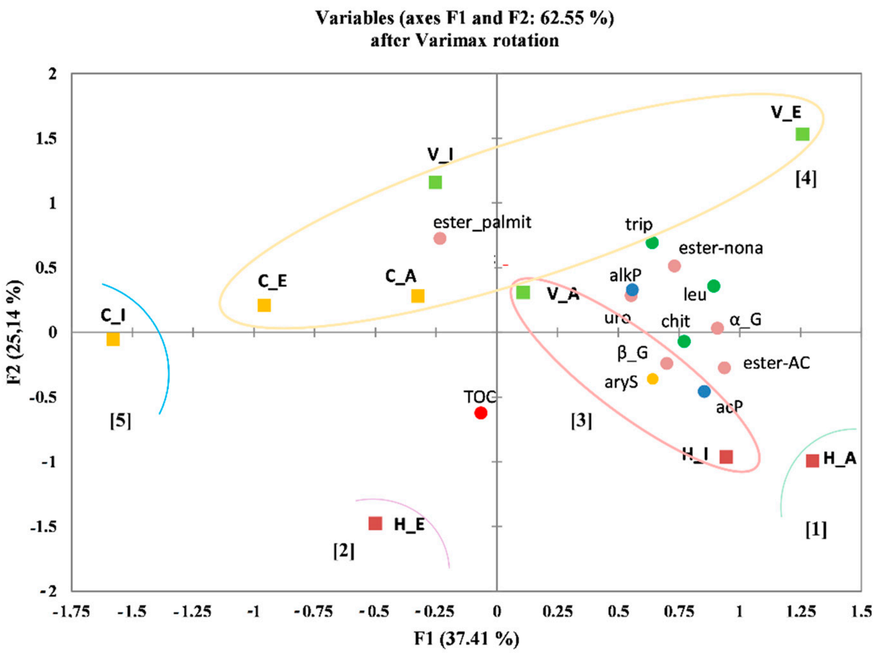

Figure 6. Principal component analysis (PCA) showing F1 and F2 axes that explained the 62.5% of total variability for 3 (Table 3) types of farming management systems: abandoned -A, extensive -E, and intensive -I. Factors loaded (colored circles) were: total organic carbon (TOC) contents, nitrogen (TN) content, ratios of TOC to TN (C/N), microbial biomass carbon (Cmic) (red cycles) and enzymes activities. Different colors of the circles refer to the implication to a specific geo-biochemical cycle: sulfur cycle-yellow; carbon cycle-red; nitrogen cycle-green, and phosphorus cycles-blue).

F1, the first component, was positively related to TOC and palmitate-esterase enzyme, whereas F2, the second one, was correlated to all the other enzymes. The farming management systems were distributed in a clear pattern along the FA biplot showing the suitability of the selected soil parameters to identify the differences between the tested species and farming management. Five groups have been identified, according to AHC, and showed in Figure 6 using different colors of perimeter of polygons. Polygons indicate 95% confidence of the standard error of factor scores. Variance decomposition for the classification showed within-class 54.2% value, while between-classes 45.8%. H_A, H_E, and C_I clustered alone in group 1, 2, and 5 respectively (Figure 6). These findings showed they were the most contrasting farming systems. V_A and H_I clustered together (group 3) and they showed low dissimilarity to HA (Supplementary Materials). All the other farming systems were clustered in group 4.

4. Discussion

The agroecological transition is nowadays the key strategy for the sustainability of agri-food chain in accordance with European Green Deal (EGD) and European Pact for Climate, and specifically the European strategy for biodiversity and Farm to Fork [52,53].

The safeguard of terrestrial biodiversity passes through the sustainable management of the natural ecosystems and the functional maintenance of the agricultural landscape, highly endangered in marginal areas. Traditional agriculture typical of family farming, such as those that generally prevail in marginal areas, intrinsically fragile and vulnerable, represents a multifunctional land uses that preserves soil from erosion, biogeochemical cycles from alteration, soil fertility from impoverishment, indigenous genetic resources from disappearance, local culture and traditional agricultural practices from oblivion [18,54–56]. Against the abandonment of the countryside, the re-wilding and the reduction of yields due to climate change, it is essential the conservative management of traditional agriculture, similar in many respects to agroecological approaches, that maintains the multifunctionality and integrity of the environmental resources, mainly the soil. Safeguarding the soil functionality, including the biological diversity in all the forms in which it occurs, depends on an integrated land management [57]. In the last 50 years the study area has been subjected to strong land use changes [58,59] and recently high soil consumption [60], depopulation, and land abandonment of inner areas have been reported [61]. Furthermore, the inner areas in the central and northern Latium region exhibit a higher soil consumption than the national average [60], with significant depletion of local agrobiodiversity [18]. As regards the coastal lands, they are elected as ecologically and biologically sensitive areas due to tourism pressure, urban sprawl and consequent natural resource degradation by soil erosion, salinization, deterioration of water quality, fragmentation of natural ecosystems [62,63]. Preserving soil functionality is therefore a pivotal challenge for the sustainable development of these territories.

This study suggests that a transition to an agriculture based on agroecological principles would provide significant soil-based environmental benefits. There is a tight relationship among soils healthiness and: (i) healthy and good quality food productions, as intrinsic to the terroir concept [64]; (ii) local genetic resources conservation [18], (iii) mitigation of climate change by carbon storage [47], and (iv) environmental benefits [23].

Several studies [4,65] suggested that soil chemical, biological, and biochemical attributes could be good indicators of soil health, useful for analyzing and predicting the effect of agronomical management in agricultural systems. We have analyzed how the soil-based ecosystem services might be originated by TOC, microbial biomass, and soil enzymes in different traditional tree crops systems, under different farming models in familiar farms.

Our findings underlined that the extensive farming systems adopted by smallholder farmers, mixed cropping systems (agroforestry approach typical of extensive farming models), low level of external inputs, mechanization and yield, were the most effective management forms for preserving soil total organic carbon (TOC). In fact, in all tree crop systems (hazelnut orchards, citrus groves and vineyards) extensive farming approach was related to the highest values of TOC, in comparison to the abandoned and intensive status. Hazelnut groves showed a high provision of total nitrogen (0.21–0.25%) and the highest content of total organic carbon in all tested farming systems, values higher than 2.0% which is considered a critical threshold for agricultural soils [66]. Soil health and ecosystems services rely on microbial carbon content expressed by two pivotal indicators: microbial biomass (Cmic) and the Cmic-to Corg ratio, useful parameters to monitor soil organic matter. Together they provide a more sensitive index than TOC measured alone [33]. The microbial biomass C (Cmic) normally comprises only 1–5% of TOC. However, this percentage, called "microbial quotient," has been shown to change in a consistent way among TCs and among farming management systems. The changes in the Cmic-to Corg ratio reflect the different organic matter inputs to these soils, the efficiency of conversion to microbial C, losses of C from the soil, and the stabilization of organic C by the soil mineral fractions. Extremely high Cmic-to Corg ratio and C/N—such as for vineyards and citrus groves systems—might limit metabolic activity of microbial component (biomass production and carbon storage) and increase the catabolic process, that is heterotrophic respiration, that represents the main CO_2 emission source in agro-ecosystem [47]. For this reasons vineyards and intensive citrus groves showed lower total organic carbon content in soil. Highest Cmic and Cmic-to Corg ratio values are indicators of CO_2 loss from soils and, in the long term, to soil organic C depletion, as confirmed by lower value of TOC in vineyards and citrus groves. On the other hand, "microbial quotient" was related to total nitrogen content. Lower values of N in soil under vines and citrus groves suggested a lower turnover of fresh organic matter [67] and the presence of easily metabolizable organic substances. It is reasonable to assume that a nutritional unbalance between C and N in these systems may have altered the physiological state of microbes with changes in microbial size overtime and increase in CO_2 emission by soil [68]. Along with chemical and biological parameters, soil enzymatic activity represents another bioindicators to assess soil ecosystems status, focused on biochemical processes, useful to understand the soil organic matter dynamics, highly relevant in the current context of climate change and sustainable agricultural intensification [69]. The composition and quantity of active soil enzymes and the microbial community itself, determines the nutrient availability and thus the health of soil. In particular pools of extracellular enzyme activities (EEA) are good indicators of soil C decomposition [39]. Labile soil organic carbon pool (active pool) is the most sensitive pool in the rhizosphere, that rapidly decomposes (oxidation process) and stimulates microbial activity. Enzymes active on this substrate, such as α and β-G tested on the TCs showed as agroecosystems based on *Corylus avellana* recorded the highest β-G activity, mainly in intensive farming systems, suggesting an enrichment in fresh plant materials of a cellulolytic nature for hazelnut groves and vineyards—deciduous species—which act as substrate for the β-G enzyme. Crop residues incorporated into soil or left on the soil are mineralized by the soil biota [38], that accelerate the decomposition rate by producing enzymes and influencing the plant nutrient kinetics in soil. Crop residues are specie-related with different C/N ratio that effects on nutrient availability and microbial biomass. In all hazelnut systems and in vineyards under extensive management (based on mixed crops) the soil coverage by canopies (soil shading) can directly and indirectly affect the soil conditions (moisture) and hence soil carbon emission through soil respiration, as happens in dense forest systems. Intensive farming system models affected the process of organic matter in vineyards and citrus groves, while hazelnut groves showed great value for cellulase, xylosidase, and glucuronidase (cell, xil and uro) activity. In addition, data indicate higher carbon turnover rates in all hazelnut systems, than in the other crops. The greater values recorded for esterase enzymes (ester-AC, ester-nona, ester-palm)—an efficient indicator of microbial activity in soils [70], underlined the higher microbial substrate activity for hazelnut systems, regardless similar microbial biomass [71]. The enzymes involved in N, P, and S cycles mineralize inorganic compounds from the soil organic compounds, provide nutrients for the plant growth and soil microorganisms that, in turn, promote plant growth by other means. Overall, abandoned and extensive TCs revealed higher SEs involved in N, P, and S cycles. Particularly, regarding phosphatase activity, which plays an essential role in the mineralization of organic P, intensive farming management reduces mineralization of organic P, except for hazelnut groves where also in intensive approaches mineralization activity to make P available is preserved. Arylsulfatase activities (ArylS) showed significant differences among intensity management in farming models, and in accordance to the findings of Li and Sarah (2003) [72] it decreased with increasing aridity in Mediterranean climate.

5. Conclusions

The role of farmers in preserving soil-based ecosystems services is a scientific topic of growing interest. We focused our investigation on the role of different agricultural management models (intensive, extensive, abandonment) in traditional cropping areas, where smallholder farms are prevalent. It is widely recognized that smallholders, that represent 67% of all farms in the EU, also preserve natural capital by assuring high level of biodiversity, landscape complexity, and cultural values. Transition toward sustainable food and agriculture must start from smallholder farms, delineating site-specific crop management approaches helpful in addressing spatial variability effects for adopting precision farming practices, as promoted by European Commission in COM (2019) 640 final.

This paper contributes to highlighting the role of smallholder farming for agro-ecosystem healthy and for pivotal soil-based ecosystems services, like TOC and precious enzymatic activities that support geo-biochemical cycles, when extensively managed. Many environmental transformations, together with socio-economic changes, have caused a decrease of family farming, that is based on the traditional land management approach, traditional agricultural practices of high multifunctionality. As a consequence, to land abandonment, natural recolonization of former cultivated land has occurred together with re-wilding and forest advancement with losses in biodiversity and soil-related ecosystem services. Nonetheless, fragmented patches of tree-crop-based traditional agricultural systems have survived based on local genetic resources, like vineyards, hazelnuts groves, and citrus orchards. If maintained in the traditional asset they represent precious spots for preserving soil-based ecosystem services. Both the intensification and the abandonment led to a depletion of soil functionality, hence extensive management should be incentivized by policy measures aiming to preserve the essential role of soil in the agro-ecosystems.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/su13073967/s1. Figure S1: Dendrogram of similarities among all tested conditions based on soil quality traits. H, hazelnut orchards, C, citrus groves, V, vineyards; I, intensive cultivation, E, extensive cultivation, A, abandonment, Table S1: List of enzymes (name and abbreviation) used to assess the impact of TCs also on biogeochemical cycle. It showed also the main substrate for each enzyme, the soil function, and references.

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