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Environmental determinants of plant species diversity in organic and conventional vineyards

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ABSTRACT

The factors affecting the plant biodiversity in organic (manure application) and conventional vineyards (variety "Agiorgitiko for both) in southern Greece were examined separately for each vineyard type. The index for plant biodiversity was chosen to be the Shannon one (SH). The Pearson correlation coefficients disclosed that the common factors in both vineyards types affecting the SH were the concentrations of the soil organic C and organic N, the nitrates –N, the available (Olsen) P, available Cu, exchangeable K and the $CaCO_3$ percentage. The C/N ratio in soils affected positively and significantly the SH index in both vineyards types. That means that the supply of N is not a problem with regard to decomposition but the organic C as a source of energy can be a limiting factor to plant diversity. The earthworm population density in the two vineyards types was also a significant positive factor to the SH. The concentrations of the available Mg, Zn and ammonium-N in soils affected the SH index significantly only in the conventional vineyards although their concentrations in soils did not differ. We can conclude that chemical fertilization can also affect plant variability.

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Introduction

Natural soils are complex systems characterized by a large diversity of components linked together by strong feedback interactions, which in turn modify the initial state of the (eco) system (Havlicek and Mitchell 2014). With regard to plants, soils can affect plant physiological processes while plants can also change soil processes (Buchholz et al. 2017). This rather slow feedback stands for natural soils. Biodiversity in natural soils has evolved from these slow processes. In disturbed soils, the rules of nature have to be observed to nullify the anthropogenic effects. It has been found that to reverse desertification and reestablish plant cover the ecosystems functions related to the cycling of the organic carbon, organic nitrogen, phosphorus and potassium are very crucial (Qiu et al. 2018).

Agricultural practices drastically affect the various physical and chemical processes and unlike the natural ecosystems, they take place in a short time and plants follow different evolution paths. This drastic effect on soils is not always desirable for the soil itself and generally the plant diversity (Godfray et al. 2010; Godfray and Garnett 2014). In the last years, more and more farmers have dealt with organic farming. The latter is usually associated with reduced disturbance intensity (Reganold, Elliot, and Unger 1987).

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Among the types of organic fertilizer applications, manure amendments are favored for increasing soil organic carbon stock and supplying nutrients (Zhu et al. 2007; Zhang et al. 2009; Li et al. 2017). The effects of organic farming on biodiversity have been studied and the results vary (Hole et al. 2005; Bruggisser, Schmidt-Entling, and Bacher 2010). All these effects have been examined in comparison with the conventional farming. So far, no one has examined the factors that influence biodiversity in each farming type. The aim of this work was to study the factors that influence plant biodiversity in conventional and organic vineyards separately for each one. The index of biodiversity was chosen to be the Shannon one (SH). It was decided that the soil properties, including the density of the earthworm population, would be the independent factors. The earthworms are not exactly a soil property, but their importance to improving soil structure and quality are well known (Clements, Murray, and Sturdy 1991; Pèrés et al. 2008; Bertrand et al. 2015).

Recently, the same vineyards were examined in terms of their effects on soil properties (Michopoulos and Solomou 2019). Here the aim is different but where appropriate, to save space and avoid repetition the authors refer to the above mentioned work.

Materials and methods

Site description

The study area (Figure 1) is included in the *Quercetalia ilicis* vegetation zone, and *Quercion ilicis* and Oleo-Ceratonion subzones. The climate is typical Mediterranean with dry and warm summers and mild winters with a mean annual air temperature of 16.0 °C and mean annual rainfall of 560 mm (Hellenic National Meteorological Service of Greece 2010).

The soil parent material is mainly hard and soft limestone often mixed. The altitude of the vineyards is about 350 m and the average age of both conventional and organic vineyards is about 15 years. Both vineyards types have a density of 4,000 vines per ha each. Prior to the

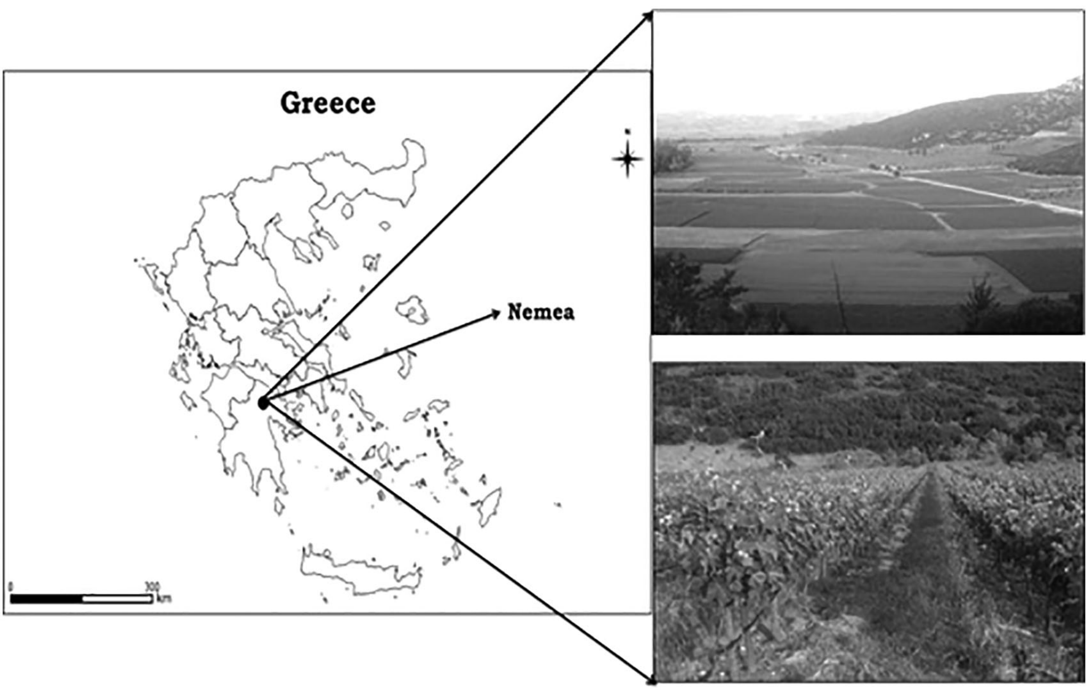

Figure 1. Study area (made by Dr. A. Solomou with ArcGIS 10.2.2).

establishment of the vineyards, the land was used for cereal cultivation for more than 50 years. The shape of all vineyards is a square and the average area of each vineyard is 0.43 ha for the conventional and 0.55 ha for the organic vineyards.

Vegetation

In the vineyards, the dominant species are herbaceous plants. More specifically, in the conventional vineyards the species (according to occupied area) are *Cynodon dactylon* (L.) Pers., *Rhaphanus raphanistrum* L., *Anthemis chia* L. *Malva sylvestris* L and in the organic vineyards: *Sinapis arvensis* L., *Chenopodium album* L., *Anthemis chia* L. *Stellaria media* (L.) Vill.

Fertilization

The conventional vineyards receive fertilization of a Nitrogen, Phosphorus, Potassium (NPK) 11-15-15 in granular form once a year in February or March. The organic vineyards are fertilized with manure derived from organic livestock farming (sheep). Details of the fertilization and irrigation of both vineyards types can be found in Michopoulos and Solomou (2019).

Experimental design and sampling

For this work, 15 vineyards receiving conventional fertilization and 15 vineyards fertilized with manure were randomly collected for soil and plant sampling. The soil samples were collected in the spring of 2015 and 2016.

Soil sampling

Five soil samples from each vineyard were collected every 10 m at a depth of 0–20 cm along the diagonal of the square shape of vineyards. The depth 0–20 cm was chosen because it is the layer from which nutrients are taken up to a large extent. The soil collection was done with a shovel after the Litter layer (L) surface layer was removed. The five samples formed a composite sample. At the end, we had 15 composite samples from the conventional vineyards and 15 ones from the organic vineyards.

Physical and chemical analysis of soils

The properties determined were: texture, calcium carbonate ($CaCO_3$) content, pH, exchangeable cations (Ca, Mg, K and Na), cation exchange capacity (C.E.C.), Organic C, organic and inorganic nitrogen (NH_4+NO_3-N) N, available phosphorus (Olsen P) and available (DTPA) trace elements (Fe, Zn, Mn and Cu). Details of the analytical methods are found in Michopoulos and Solomou (2019).

Plant and earthworm samplings

The sampling of herbaceous plants was carried out in May 2015 and 2016 in randomly selected plots of 0.25 m^2 (0.5 m × 0.5 m) each, where the number of species and their abundance were estimated (Cook and Stubbendieck 1986; Solomou and Sfougaris 2011, 2013; Solomou et al. 2019). The earthworm extraction was carried out during March 2015 and 2016, when earthworm populations were most active and extraction efficiencies were most efficient for all species. More specifically, four soil samples (each occupying a 0.25 m^2 area) were taken randomly from each vineyard type and the earthworms were extracted with the formaldehyde solution method (Raw 1959; Solomou et al. 2012; Solomou, Sfougaris, Kalburtji, et al. 2013; Solomou, Sfougaris, Vavoulidou, et al. 2013).

Atmospheric temperature and humidity

The atmospheric temperature and humidity were measured daily with an automatic device installed in each plot. At the end, the average annual temperature and humidity were calculated for each plot and plotted against the Shannon index.

Statistical analysis

The average values of the soil properties were calculated together with the coefficients of variation as the percentages of the standards deviation over the means. We examined the Shannon (SH) plant diversity index in organic and conventional vineyards, with the Species Diversity and Richness IV software (Seaby and Henderson 2006). The Shannon index (SH) index takes into account both species abundance and species richness and it is the most commonly used index (Heuserr 1998; Kent and Coker 1992). For any sample population the SH is calculated as:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

where, s equals the number of species and p_i is the relative cover of ith species (Whittaker 1972; Pielou 1975) (for a detailed description of the mathematical background for this index, see Seaby and Henderson 2006). The Pearson correlation coefficients were employed to account for the correlations between the variables measured (ED-Earthworm Density, Org. C, NO_3 – N, NH_4-N, $CaCO_3$, pH, CEC, Air temperature-AT, Relative Humidity - RH, C/N, Ca, Mg, Mn, Na, Fe, Zn, N, K, Cu, P Olsen, Clay percentage in soils) and Shannon plant diversity index in the organic and conventional vineyards. Before the calculation of the Pearson correlation matrix, the data had to be transformed to logarithms to conform to the normal distribution criterion.

Results

The average values of the soil properties of the vineyards are shown in Tables 1 and 2. The Pearson correlation coefficients showed that there were soil parameters such as the population of earthworms, the available organic C, organic N, nitrate-N, the C/N ratio, the available P, exchangeable Ca, exchangeable K, available Cu and $CaCO_3$ on which the SH plant diversity index depended significantly, for both vineyards types. On the other hand, the exchangeable Mg, available Zn and ammonium –N affected the SH plant diversity index in the conventional vineyards significantly, whereas there was no such relationship in the organic vineyards.

Table 1. Soil parameters.

Vineyard type	pH	$CaCO_3$	Org. C	Clay	Ca	Mg	K	Na	ED
Conventional	8.28	7.78	1.42	37.4	31.9	1.17	0.98	0.01	4.1a
	(2.1)	(81)	(47)	(16)	(22)	(38)	(32)	(35)	(36)
Organic	8.12	6.48	1.94	29.8	30.3	1.49	1.12	0.01	12.2b
	(4.5)	(100)	(23)	(30)	(14)	(47)	(33)	(15)	(47)

$CaCO_3$, Org.C and Clay are expressed in percentages (%), Ca, Mg, K and Na in $cmoles_c\ kg^{-1}$. The ED is expressed in numbers of earthworms/m^2.The numbers in parenthesis are the CVs (%).

Table 2. Soil parameters.

Vineyard type	C.E.C.	P	Mn	Fe	Cu	Zn	C/N	Org. N	NH_4_N	NO_3_N
Conventional	21.9	18.6	102	23.7	8.47	1.75	9.07	1559	13.6	9.97
	(15)	(55)	(58)	(30)	(53)	(33)	(30)	(27)	(53)	(61)
Organic	26.1	11.9	94.2	31.8	12.7	2.20	9.83	1984	13.8	13.6
	(10)	(55)	(60)	(23)	(34)	(42)	(17)	(16)	(59)	(60)

C.E.C. is expressed in $cmoles_c\ kg^{-1}$, P, Mn, Fe, Cu, Zn, Org. N, NH_4^+ -N and NO_3^{-1} –N in $mg\ kg^{-1}$. The numbers in parenthesis are the CVs (%).

Discussion

When examining plant variability, we have to make the distinction that differences in soil properties do not entail differences in the SH index. In Tables 1 and 2, there were only four significant differences out of 18 compared (organic C, CEC, available Fe and Cu) (Michopoulos and Solomou 2019) and nine common soil parameters that significantly affected the SH index in each vineyard type.

The SH index depends on fertility and fertility was found to depend on common and/or different factors in each vineyard type. In both vineyards types, the SH depends positively on the organic C and organic N as well as the C/N ratio. The higher the ratio, the higher the biodiversity. One would expect the opposite since in natural soils the C/N ratio is an index of decomposition rates. The finding in this work means that decomposition due to low N supply is not a problem in these soils but as the organic C is a source of energy for microorganisms, its deficiency can slow down the decomposition of organic matter.

Another common factor was the nitrate N (Table 3). This form of N resulted from the nitrification of N compounds. There is a feedback between the availability of N and the SH. In general, the rates of N mineralization increase with plant species diversity (Dybzinski et al. 2008; Zak et al. 2003). On the other hand, composition and diversity affect soil fertility through the differential species effects on nutrient inputs. For example, plants that form associations with N fixing bacteria can increase N availability in soils. Like every functional group, N fixers are more likely to be present in diverse communities.

Table 3. Pearson correlation coefficients of soil parameters with the Shannon diversity index in the two types of vineyards.

	Organic vineyard	Conventional vineyard
Earthworm density	0.82**	0.72**
Org. C	0.96**	0.79**
Org. N	0.69**	0.63*
NO_3 – N	0.72**	0.79**
NH_4-N	0.16	0.33*
$CaCO_3$	0.71**	0.69**
pH	0.31	0.29
CEC	−0.20	0.22
Air temperature	−0.18	−0.20
Relative humidity	−0.16	0.10
C/N	0.66**	0.57*
Ca	0.63*	0.51*
Mg	−0.26	0.44*
Ca/ Mg	0.23	0.24
Mn	−0.35	−0.45
Na	−0.19	0.46
Fe	−0.55	0.09
Zn	0.25	0.68*
N	0.69**	0.63*
K	0.60*	0.63**
Cu	0.59*	0.77**
P Olsen	0.58*	0.65*
Clay	0.17	−0.58

*and ** denote significance level at 0.05 and 0.01 probability levels.

There are other common nutrients in both vineyards type the concentrations of which significantly affected the SH. Such nutrients were the available P and K. Maestre et al. (2012) and Korol, Ahn, and Noe (2016) stressed the importance of N and P cycling with regard to plant richness. Potassium increases the resistance of plants to dry climates such as in the Mediterranean zones and P gives the energy to all biological reactions and therefore both elements contribute to the increase of biodiversity (Wang et al. 2013). The Cu content affects positively the SH index in both types. As the Cu content in soils is largely the result of the application of bordalese in the vine leaves, the positive relation could be attributed to the lowering of the population of pathogens rather than being a beneficial soil property.

The SH was affected positively by the earthworm density in both vineyards types. It is known that the application of manure increases the buildup of earthworm activity and populations in cropped soils (Sharpley et al. 2011). In this work, it was also the conventional vineyards that were affected by the earthworm population in terms of the plant diversity. This was either done indirectly by promoting soil fertility or directly by suppressing soil born pests, a role that sometimes is forgotten (Plaas et al. 2019). There is also a feedback effect as the earthworm density can be increased proportionally with plant biomass.

The dependence of the SH index on the $CaCO_3$ content (and Ca therefore) is probably not due to the current environmental conditions but to an old floristic adaptation. The plants in both vineyards types are the results of an evolution that took place long time ago. Ewald (2003) argued that Pleistocene range conditions caused the extinction of more acidophilus species than calciphilus because acid soils were much rarer when refugial areas were at their minimum. Therefore, calciphilus species developed an ability to multiply in calcareous soils.

There were three elements the concentrations of which were significant with regard to the SH index only for the conventional vineyards. Those were the ammonium N and the exchangeable Mg and available Zn. The concentrations of these elements did not differ significantly in the soils of the two vineyards types (Michopoulos and Solomou 2019) and one would expect that their effect on the SH index would have been identical in the two types. As in the case of ammonium-N, the Mg and Zn are provided by chemical fertilization. The dependence of the SH index on these elements means that without fertilizers the plant diversity might have been different in the conventional vineyards.

The temperature and relative humidity did not affect the SH index. Of course if the vineyards had been situated in different latitudes, these parameters could have been much more influential. It seems that in the same area the soil factors and the application of either manure or inorganic fertilizers play the most important roles.

Conclusions

More common than different soil factors affected the plant biodiversity in the two vineyards types. It is interesting that the C in soils as an energy source can be a limiting factor for plant biodiversity in both vineyards types. This finding resembles the dependence of the immature soils on organic matter.

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Conflict of interest

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