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Exploitation of soil properties for controlling herbaceous plant communities in an organic cultivation of *Lippia citriodora* in the Mediterranean landscape

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Abstract

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Soil plays an important role in the creation and heterogeneity of habitats and thus can cause changes in plant structure, diversity and density. The objective of this study was to assess the effects of soil properties on herbaceous plant density in an organic cultivation "*L. citriodora*".

The soil properties of the adjacent natural environment (11 years abandoned ecosystem), which served as a control were also examined and compared with those of the organic cultivation "*L. citriodora*". The study was conducted in April-May 2016, 2017 and 2018 of central Greece. In total, 29 species of herbaceous plants (20 plant species in the *L. citriodora* ecosystem and 14 plant species in an abandoned ecosystem, $p < 0.05$) were recorded in the study area. Our study highlights an increase in herbaceous plant density with increasing soil organic matter, P and K in an organic cultivation of "*L. citriodora*" ecosystem. Conclusively, this study could be exploited as a valuable tool to the scientific and agricultural community because of that the soil-plant relation is important from the conservation biology point of view and aid in the implementation of preventive plans for the biodiversity conservation.

Keywords: aromatic plant; density; exploitation; environment; Greece

Introduction

Aromatic and medicinal plants constitute a consistent part of the natural biodiversity endowment of many countries worldwide. These plant species provide an important contribution to health, local economies and cultural integrity (King, 1992; Okigbo, 2008). One of the most important aromatic and medicinal plants is *L. citriodora* (Paláu) with important health benefits and ecosystem services. It is a deciduous shrub with a height between 1.5-2 m and belongs to the family *Verbenaceae*. Also, it originates from South America (Duarte et al., 2007) from where it moved to Europe in the 17th century by Spanish and Portuguese explorers and cultivated for the production of essential oil. Nowadays, it is cultivated in many countries in Latin and Central America, in Southern Europe (Greece, France), in Northern Africa (Algeria, Morocco) China, and Iran. *L. citriodora* is a medicinal and aromatic plant with many uses (e.g. cooking, cosmetics). The fascinating health benefits of *L. citriodora* include its ability to protect muscles, reduce inflammation, boost the immune system, calm the stomach, reduce fevers, soothe nerves, and clear up congestion. It is also popularly used for weight loss (Maloumi, 2016).

According to literature few studies have taken place in Greece to the *L. citriodora* essential oil (Fitsiou et al., 2016; Kazi et al. 2017; Fitsiou et al., 2018). It is noteworthy, the effect of plants on soil characteristics have been known since the development of the concept of the factors of soil formation (Jenny, 1941). Plants influence the soil by recycling different nutrients, which suggests that to increase the productivity of the land both soil and plant should be studied simultaneously. Hence, the major goal of this study was to understand the inter-relation of soil properties and herbaceous plant density in an organic cultivation of "*L. citriodora*" ecosystem of central Greece for which there are no studies in the literature. This study will contribute to the integration of biodiversity conservation with ecologically sustainable agriculture and conservation of agroecosystem.

Material and Methods

Study area

The present study was conducted in Thessaly plain (Experimental Farm of the University of Thessaly, Velestino, central Greece, 2014) (Figure 1). The climate of the area characterized as typical Mediterranean and continental with hot and dry summer followed by a humid and cool winter. The soil characterized as clay loam with high amount of calcium and good drainage (Mitsios et al., 2000).

Sampling

The sampling of herbaceous plants was done during the April-May 2016, 2017 and 2018 of central Greece in randomly selected plots of 0.25 m^2. In each plot plant species richness and density in an organic *L. citriodora* and neighboring abandoned ecosystem was recorded (Cook & Stubbendieck, 1986). In each plot composite soil samples were taken by the randomized method (soil depth: 0–40 cm). Soil organic matter (%) (Nelson & Sommers, 1982), pH (McLean, 1982), $CaCO_3$ (Nelson & Sommers, 1982), texture (clay, silt, sand) (Bouyoukos, 1951), P (Olsen & Sommers, 1982), K and Mg (Thomas, 1982) were measured (Table 1).

Statistical analysis

All data were evaluated for normality and homogeneity of variances with the use of Kolmogorov-Smirnov and Bartlett's tests. When normalization of the data was necessary, the [log(x+1)] transformation was used (Zar, 1999). Generalized Linear Models were applied to analyze the soil properties (soil organic matter (%), pH, $CaCO_3$, texture (clay, silt, sand), P, K and Mg explaining most variance of herbaceous plant density (McCullagh & Nelder, 1989). Soil data were log-transformed to avoid possible effects from their different value ranges. Models were built using a stepwise selection procedure to select significant ($p<0.05$) relevant explanatory variables. We selected a stepwise model selection procedure, beginning with a full model and re-introducing one variable at each step (Pearce & Ferrier, 2000). The model with the lowest value for the Akaike's Information Criterion (AIC) was selected as the best (Akaike, 1977; Zar, 1999; Bio et al., 2002). All the above analyses were accomplished with the application of IBM SPSS Statistics Version 23 for Windows (IBM, 2015).

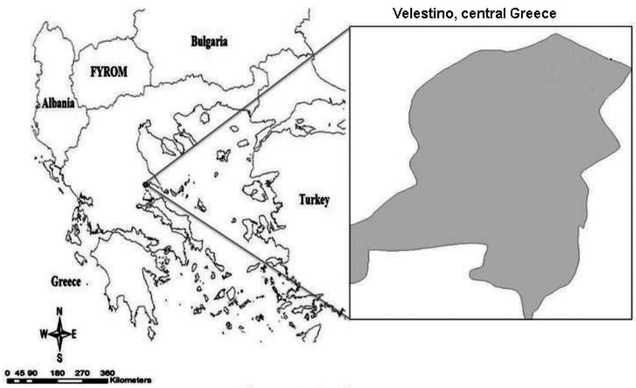

Fig. 1. Study area

Results and Discussion

Herbaceous plant composition

Agricultural landscapes represent a cultural landscape group. The basic elements of the rural landscapes are the agroecosystems. Agro-ecosystems maintain large numbers of flora and they are considered to be agricultural systems of high ecological value for biodiversity (high-nature-value farming systems). In total, 29 species of herbaceous plants (20 plant species in *L. citriodora* ecosystem and 14 plant species in an abandoned ecosystem) were recorded in the study area (Table 2).

The most frequently occurring plant was *Avena sterilis* L. (Family: *Poaceae*) (Status: Native, Chorology: Mediterranean-SW Asian, Life-form: Therophyte, Habitat: Agricultural

Table 1. Soil properties

Ecosystem	Sand (%)	Clay (%)	Silt (%)	pH	Conductance	$CaCO_3$ (%)	O.M. (%)	P (mg/kg)	K^+ (mg/kg)	Total N (%)
Organic	39	14	47	7.7	302	12.5	2.5	42	1118	0.08
Abandoned	32	20	48	8	250	9.3	1.9	34	1012	0.07

Table 2. Herbaceous plant species in *Lemon verbena* and abandoned ecosystems (+: presence)

Herbaceous plant species	*Lemon verbena* ecosystem	Abandoned ecosystem
Aegilops geniculata Roth.	+	+
Amaranthus albus L.		
Amaranthus deflexus L.	+	
Anthemis arvensis L.	+	
Arctium lappa L.	+	
Asphodelus aestivus L.		+
Avena sterilis L.	+	+
Bellis perennis L.	+	
Briza maxima L.		
Calystegia sepium (L.) R. Br.	+	
Capsella bursa-pastoris (L.) Medik.	+	+
Chenopodium album L.	+	
Cynodon dactylon (L.) Pers.		+
Dactylis glomerata L.		
Fumaria officinalis L.	+	+
Glaucium flavum Crantz	+	+
Heliotropium europaeum L.	+	+
Lamium amplexicaule L.	+	+
Lolium perenne L.	+	+
Malva sylvestris L.		+
Papaver rhoeas L.		
Polygonum aviculare L.	+	
Sinapis arvensis L.	+	
Sonchus arvensis L.	+	
Sorghum halepense (L.) Pers.	+	
Stellaria media (L.) Vill.	+	+
Tordylium apulum L.		+
Tribulus terrestris L.		+
Veronica persica Poir.	+	
Total	20	14
Mean (±standard deviation) of herbaceous plant density	7.14±0.32	4.15±0.54

and Ruderal habitats) in both types of ecosystems and *Chenopodium album* (Family: *Chenopodiaceae*) (Status: Native, Chorology: Cosmopolitan, Life-form: Therophyte, Habitat: Agricultural and Ruderal habitats) in *L. citriodora* ecosystem.

According to Dimopoulos et al. (2013), these plant species are characteristic of agroecosystems. *Avena sterilis* and *Chenopodium album* are highly invasive in cultivated farms and have probably already invaded many suitable regions of the Greece. More specifically, *Chenopodium album* is a plant index in the *L. citriodora* ecosystem as it can indicate the presence of humus and nitrogen in the soil (WILDWATERWALL, 2018).

It is noteworthy that plant index are good indicators of environmental health because connect the ground to the air. In particular, they draw most necessary data from the ground but are also directly related to its state of the air because their peaks are gas collectors' ingredients. Thus, the chemical composition of plants is an important indicator of contamination of the plant growth areas when it can be compared with corresponding plant values that grow in a healthy environment (Figure 2).

Soil properties affecting the species density in herbaceous plant communities

Plant population is the most important level of plant ecology, conjunctive plant individuals with communities and ecosystems. The ecological patterns of a plant population are characterized by the dynamics of their population, as well as the correlations between the population and the external environments (Odum, 1971).

This study highlights the importance of ecological interactions between the soil properties and herbaceous plant density only in "*L. citriodora*" ecosystem. More specifically, Generalized Linear (Table 3) Models showed good to excellent ability to "interpret" the dependent variable (herbaceous plant density) (based on adj. R^2) ($p < 0.05$). The model showed that soil organic matter, P and K had positive effects on herbaceous plant density and interprets 81% of the total variation of herbaceous plant density.

According to literature (Cirujeda et al., 2011) management practices and environmental factors have been found to be the most important factors that explain herbaceous plant species composition, diversity and density. As regard the physical characteristics of soil, these are a key factor which defines its own physical consistency where the majority of the biological procedures have an active role, while in parallel the chemical elements specify the properties of a certain soil (De Vos et al., 1994; Hassink, 1997). Several physico-chemical properties like soil temperature, moisture content, pH, total, organic carbon, total nitrogen and phosphate influence soil activities and uptake of water and nutrients by roots of the plants (Arunachalam et al., 1997).

More specifically, the organic matter of a soil contains many qualities such as preserve nutrients, upgrade the nutrient circle, construct soil composition, improve water permeability, decrease soil density, resists to fast transition in soil pH operating as power source for many microorganisms and raise assimilation of Cu, Mn and Zn in the soil as a result all the above mentioned favor the plant composition and population (Borah et al., 1992).

Also, soil Phosphorus (P) is natural substance which exists in organic and inorganic structures while is encountered in soils, water and almost all living organisms. Every structure is continuity, for a lot of P chemical mixtures, which are in harmony and extend from solution P (absorbed by plants) to stable,

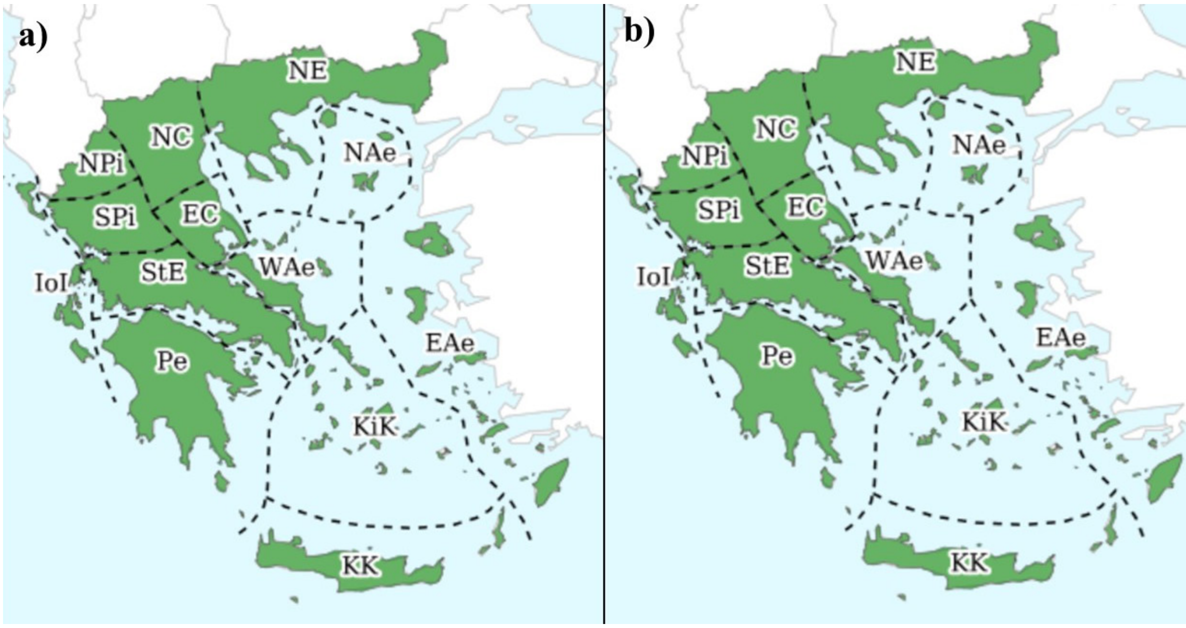

Fig. 2. Distribution of highest relative abundance plant species in Greece:
a*) *Avena sterilis* L and *b*) *Chenopodium album

Note: IoI – Ionian Islands, NPi – North Pindos, SPi – South Pindos, Pe – Peloponnesus, StE – Sterea Ellas, EC – East Central Greece, NC – North Central Greece, NE – North-East Greece, NAe – North Aegean islands, WAe – West Aegean islands, Kik – Kiklades, KK – Kriti and Karpathos, EAe – East Aegean islands (Dimopoulos et al., 2013)

unstable or even unobtainable compounds (the most common). It is important that Phosphorus is the most important key element in the nutrition of plants. Plants use in many ways the structures of Phosphorus, the most important is for storing and transferring the energy through the plant. Most of the plant activities including nutrient transport, photosynthesis, respiration as well as nucleic and protein acid synthesis are high-powered phosphate compounds occurring from adenosine triphosphate (ATP) and adenosine diphosphate (ADP) (Khan et al., 2010; Sharma et al., 2013).

Moreover, worthy of mentioning is the Potassium (K) element which is a major factor for determining soil fertility and plant richness and density. Plant accessibility is separated in soil solution, with interchangeable and irreplaceable formations and to exist in soil crystal lattice (Barber, 1984; Mengel & Kirkby, 1987). It plays an important role in the maintenance of plant turgor, stomatal movement, cell expansion, cation – anion balance, pH, phloem transport and protein synthesis.

Conclusions

The present results suggest that herbaceous plant density increases with increased organic matter, P and K of the soil in the organic cultivation of *L. citriodora*. These results are important as they could be exploited for understanding the ecological value and dynamics of the organic *L. citriodora* cultivation. Moreover, our findings can be a useful tool for the ecosystem's environmental protection, the wider scientific community and the general public during the current economic crisis.

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Table 3. Generalized Linear Model (McCullagh & Nelder, 1989; Zar, 1999) of herbaceous plant density

Ecosystem	F	Adjusted R- squared	Likelihood ratio χ^2	Akiake information criterion	P	Model
Lippia citriodora	11.38	0.81	18.64	39.12	0.00	1.46+16.23(SOM)*++2.25(P)** + 1.39 (K)***
Abandoned	5.22	0.62	16.40	32.87	0.08	

*SOM: Soil organic matter, **P: Phosphorus, ***K: Potassium

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