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Soil fertility and plant nutrition of *Pinus pinaster* and *Pinus radiata* reforestations in Halkidiki, Northern Greece

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Abstract

Pinus pinaster Aiton (maritime pine) and *Pinus radiata* D.Don (radiata pine) are both coniferous species not native in Greece, which were artificially installed in Halkidiki, Northern Greece, since the early 1970s. The research was performed to estimate the soil conditions of both conifers in two different areas, where the reforestation has been successful. The best site quality stands were selected, having particularly deep soil. Samples of soil, litter and needles were taken for both species from 16 different sample plots in two sites: Stratoni and Sithonia. From the results, higher concentrations of most soil nutrients, as well as better absorption of P and N by trees, were found in Stratoni for both conifers. Tree dimensions for both conifers are greater in Stratoni, corresponding to the higher nutrient content and an observed higher humidity. The concentrations of nutrients in soil, litter and foliage for each conifer species were assessed according to the literature.

Key words: conifers, litter, maritime pine, Mediterranean ecosystems, Monterrey pine, needles, soil nutrient content.

Introduction

Soil fertility plays a decisive role controlling the growth of plants in forest ecosystems, but forests also have a greater influence on the soil conditions than most of other plant ecosystem types (Binkley and Giardina 1998). Moreover, soil fertility plays a key role in influencing the establishment and growth of artificial forests. Viewpoints about soil fertility vary widely, so many researchers have suggested that attention should be shifted towards another concept: soil quality (Patzel et al. 2000).

Studies on litter decomposition are very important for understanding the way a forest ecosystem functions. Litter decomposition controls the nutrient release rate and the availability of soil nutrients to plants (Kurz et al. 2000). Only a small pro-

portion of nutrients used by plants (S, Ca, Mg, K) comes from releases of minerals from soil. The largest proportion comes from the mineralization by micro-organisms of the soil organic matter, including the organic material fallen from the trees through litterfall (Swift et al. 1979). Furthermore, nutrients in foliage influence the dynamics of tree nutrition, affecting carbon assimilation and wood yield (Sheriff et al. 1986).

Pinus pinaster Aiton and *Pinus radiata* D.Don are both fast-growing conifers, suitable for wood production (Alía et al. 1997). *P. pinaster* is a native Mediterranean conifer plant, used in afforestation mainly in Southwestern Europe, but also in Africa, New Zealand and Australia (Ferreira-Santos et al. 2020). The Mediterranean Basin is also considered a typical habitat for *P. radiata*, a native South American conifer, but with up to 93 % successful reforestations in many Mediterranean areas around the world (Richardson and Rundel 1998, Hermoso et al. 2007, Arias-Rodil et al. 2015). *P. pinaster* and *P. radiata* were both artificially reforested in Halkidiki, Northern Greece, mainly in the early 1970s (Varelides and Kritikos 1994). Both seemed to fail, as extensive reforestations were destroyed by drought (Papamichos and Alifragkis 1980), chlorosis in young plants occurred (Nakos 1978), both conifers showed a low life expectancy, compared to endemic pine species, such as *P. brutia* and *P.nigra* (Zagas and Ganatsas 2001).

The H:D ratio is used to quantify the risk of storm damage, using classic or modern models (Ogana et al. 2020). According to Sudmeyer et al. (2004), *P. pinaster* and *P. radiata* have similar root lateral extent and the greatest root density within 0.5 m of the soil surface.

Regarding soil nutrient content, Knicker et al. (2005) found concentrations of N between 0.07 and 0.11 % in topsoil (0–20 cm) of a natural *P. pinaster* forest in Spain. Martins et al. (2009) found total N 0.47 % and P 2.06 $mg \cdot 100^{-1}$ in topsoil of *P. pinaster* on sandy soils in Galicia, Northwestern Spain. Respectively, Hopmans and Elms (2009) found the following concentrations: N 0.7 %, P 0.57 $g \cdot kg^{-1}$, K 0.79 $g \cdot kg^{-1}$, Ca 6.95 $g \cdot kg^{-1}$, Fe 1.946 $mg \cdot kg^{-1}$, Mn 382 $mg \cdot kg^{-1}$, Zn 13.7 $mg \cdot kg^{-1}$ and Cu 3 $mg \cdot kg^{-1}$ in litter of an Australian *P. radiata* plantation on podzolized sands. In addition, Turner and Lambert (1988) found N 0.48 %, P 0.63 $mg \cdot g^{-1}$ in litter, N 0.09 %, P 0.12 $mg \cdot gr^{-1}$ and N 0.05 %, P 0.105 $mg \cdot gr^{-1}$ at two soil depths (0–7.5 cm and 30–37 cm), respectively, in Australian *P. radiata* plantations. Among the mineral nutrients, soil nitrogen status is deliberated as being the primary regulating factor, while phosphorous is usually considered as a limiting nutrient because of the low quantity in circulation in major forests (Devi and Yadava 2007, Krishna and Mahesh 2017).

Regarding nutrient content in foliage, Butcher (1977) found the following concentrations: N 0.8 %, P 0.71 $mg \cdot g^{-1}$, K 6.02 $mg \cdot g^{-1}$, Ca 1.5 $mg \cdot g^{-1}$, Mg 1.94 $mg \cdot g^{-1}$, Mn 18.13 $mg \cdot kg^{-1}$ and Zn 25.67 $mg \cdot kg^{-1}$ in needles of *P. pinaster* plantations in Australia. Respectively, Romanyà and Vallejo (2004) found N 1.62–1.73 %, P 1.17–1.57 $mg \cdot g^{-1}$ K 8.08–6.76 $mg \cdot g^{-1}$ and Mg 1.16–2.02 $mg \cdot g^{-1}$ in foliage of *P. radiata* plantations in Spain. Moreover, Hopmans and Elms (2009) found N 1.29 %, P 1.32 $mg \cdot g^{-1}$, K 7.31 $mg \cdot g^{-1}$, Ca 6.8 $mg \cdot g^{-1}$, Mg 2.03 $mg \cdot g^{-1}$, Fe 83 $mg \cdot kg^{-1}$, Mn 534 $mg \cdot kg^{-1}$, Zn 16.2 $mg \cdot kg^{-1}$ and Cu 2.76 $mg \cdot kg^{-1}$ in foliage of *P. radiata* plantations in Australia. Merino and Edeso (1999) found N 1.48 %, P 2.02 $mg \cdot g^{-1}$, Mg

1.21 mg·g^{-1} and Ca 6.41 mg·g^{-1} in the foliage of *P. radiata* after intense soil treatment in Northern Spain.

Temperature, precipitation and chemical content of litter strongly control rates of litter decomposition, influencing the recycling of nutrients and thus ecosystem fertility (Aerts et al. 1997, Brant et al. 2006, Smyth et al. 2015). The most favourable microclimate found especially in Stratoni, due to humidity, has been pointed out by Greek forest researchers (Chatzistathis 1980).

The aim of this study is to estimate soil conditions and the differences in nutrient content between two forest sites in Stratoni and Sithonia, where both conifers managed to survive and grow.

Material and Methods

Study area

The study areas are in Stratoni at the Northeast of Halkidiki and at the peninsula of Sithonia at the South of Halkidiki. Both study areas include reforestations of both *Pinus pinaster* and *Pinus radiata* (Fig. 1). The distance between sites is more than 50 km. The elevation of sampling plots ranges from 450 to 545 m in Sithonia and from 0 to 280 m in Stratoni. Although the climate is mainly temperate and mild, it is locally influenced by topography. The dry period lasts 1.5–2.5 months, rendering the area vulnerable to fire. Average annual precipitation is 795 mm, mean annual temperature is 9.85 °C and daily mean temperature ranges from 2.1 to 21.6 °C in the study areas.

According to the ISSS Working Group RB (1998a, 1998b), the soils are Eutric Cambisols, containing shallow and moderately deep soils, developed under typical Mediterranean vegetation. Forest soil has formed on gneiss parent material in reforestations of Stratoni; correspondingly, the forest soil has formed on granite – argillic schist in reforestations of Sithonia. Pine reforestations were carried out since the early 1970s according to Greek Forest Services. Native vegetation is dominated by oaks, such as mainly kermes oak (*Q. coccifera* L.), holm oak (*Q. ilex* L.), plane trees (*Platanus orientalis* L.) or evergreen

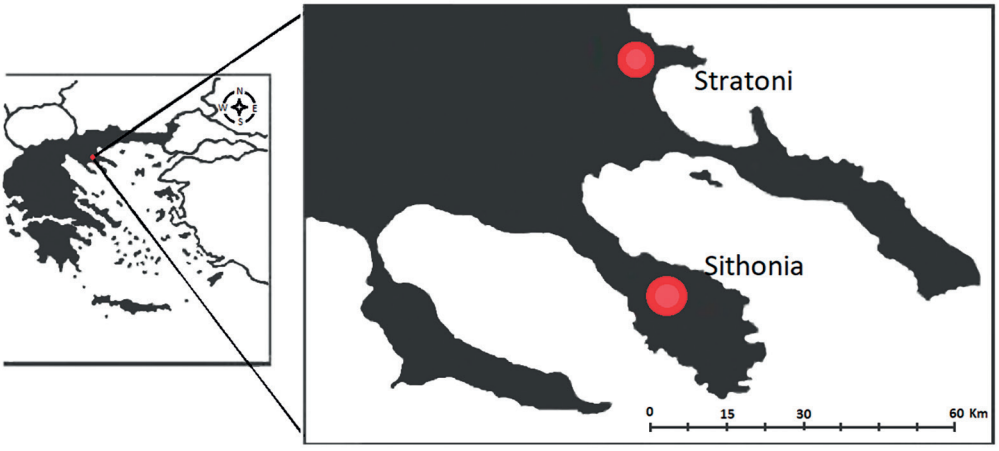

Fig. 1. The study area.

shrubs, such as tree heath (*Erica arborea* L.), strawberry tree (*Arbutus unedo* L.), Greek strawberry tree (*Arbutus andrachne* L.), rock rose (*Cistus* sp.), black alder (*Alnus glutinosa* L.), mastic tree (*Pistacia lentiscus* L.), green olive tree (*Phyllirea latifolia* L.) and turpentine tree (*Pistacia terebinthus* L.).

Sixteen sample plots were chosen, eight for both conifer species, each covering an area of 314 m^2. All sample plots were located within a pure and undisturbed *Pinus pinaster* and *Pinus radiata* plantations. The sample plots were selected by random systematic sampling for both conifers, keeping a distance of more than 2 km from each other, in order to represent different forest microenvironments. Sample plots from Stratoni were located between 24°03'39'' E latitude, 40°43'42'' N longitude and 23°54'22'' E latitude, 40°46'31'' N longitude, while sample plots from Sithonia are located between 23°58'32'' E latitude, 40°09'14'' N longitude and 24°03'44'' E latitude, 40°20'39'' N longitude. The elevation of sample plots ranges from 0 to 120 m in Stratoni and from 425 to 545 m in Sithonia. The average slope is 7–10 %, while the dominant aspect is oriented northeast.

At both Stratoni and Sithonia, eight sample plots were selected, four for *Pinus pinaster* and four for *Pinus radiata*. Sample plots were chosen according to the field- based survey data from the Greek Forestry Services. At each sample plot the breast height diameter and the height of all healthy trees was measured to assess the growth of both conifers and the differences between the two areas. The measurements of breast height diameter were carried out using a calliper and a diameter tape (accuracy 1 cm). Height measurements were carried out using a Blume-Leiss and a Haga altimeter (accuracy 0.1 m). Forked trees (in h < 1.3 m) were measured as two different trees. Field measurements were implemented in the middle of the growing period (July-August) (Dobbertin et al. 2013).

Methods

A square metallic frame with dimensions of 25×25 cm was used for the sampling of litter. Litter's samples were randomly selected in five sites per plot, separately for each organic horizon (pine needles and twigs, partially decomposed layer or well decomposed humus). The litter within the square area was transferred into labelled plastic bags. Pine needle samples, one per each sampling plot, were also selected. About one hundred and sixty litter samples and sixteen pine needles samples were transported to the Forest Soil Laboratory of Aristotle University. The collected samples were dried in an oven at 74 °C for 48 h, next the samples were weighed, grounded and prepared for analyses. Soil samples were taken from depths of 0–10, 10–20, 20–40 and 40–60 cm from two different soil profiles per sample plot. About one hundred and twenty soil samples were transferred into labelled plastic bags and transported to the laboratory. Then all soil samples were air-dried, weighed, grounded, passed through a 2 mm sieve and prepared for analyses.

Litter's and needles' chemical analyses were performed in pulverized and homogenized material. Total nitrogen (N) was estimated using Kjeldahl digestion method (Stevenson 1982). The nutrients Ca, Mg, K, Na, Fe, Mn, Zn και Cu were measured using an atomic absorption spectrophotometer (PerkinElmer, Inc., USA) in a mixed solution of HNO_3, $HClO_4$ and H_2SO_4 (5:1:0.5) (Allen et al. 1986). Phosphorus

was determined using the molybdate blue colorimetric method.

Soil N was determined using Kjeldahl digestion method (Stevenson 1982). Extractable P was also measured using the blue of ammonium sulphoparamolybdate method (Olsen and Sommers 1982). Exchangeable cations, such as Ca, Mg, and K were determined using the CH_3COONH_4 1N solution of pH 7 (Grant 1982). The micronutrients Fe, Mn, Zn and Cu were determined using the diethylenetriaminepentaacetic acid solution of pH 7.3 (Lindsay and Norvell 1978). All extracted cations Ca, Mg, K, Fe, Mn, Zn and Cu were measured using an atomic absorption spectrophotometer.

Statistical analysis

All statistical analyses were performed using the SPSS statistics software (Version 20 2014). The uncorrelated t-test is used to calculate whether the averages of two groups from different samples differ significantly from each other (Howitt and Cramer 2001). Therefore, t-tests were used to assess the significance of differences between concentrations of nutrients from the two areas. Nine dependent variables were selected for regression analysis: N (%); P, Mg, Ca, K ($mg \cdot g^{-1}$); Cu, Fe, Zn, Mn (ppm). Independent sample t-tests were used to compare means of variables (concentrations of nutrients) for soil, litter and needles from Stratoni and Sithonia, as well as to compare the dimensions of trees in both areas. In addition, *p*-values from the two-tailed probability computed using the t-distribution were compared to an alpha level of 0.05 (SAS 2008).

Results

Tree dimension measurements

The maximum total tree height was found above 20 m for both conifer species, while the maximum breast height diameter was found above 43 cm for *Pinus pinaster* and above 33 cm for *P. radiata* on the sample plots of Stratoni. Correspondingly, the maximum total tree height was found above 16 m for both conifer species, while the maximum breast height diameter was found above 26 cm for *P. pinaster* and above 22 cm for *P. radiata* on the sample plots of Sithonia.

Dendrometric variables

Table 1 shows the dendrometric variables on sampling plots, including average height (H), average breast height diameter (D), H:D ratio and tree density.

There are significant differences between the two areas in most variables. Higher values in average height and average breast height diameter are presented

Table 1. Dendrometric variables (mean ± s.d.) for *Pinus pinaster* and *Pinus radiata* in both areas.

Species	Area	H, m	D, cm	H:D	Density, ha^{-1}
Pinus pinaster	Stratoni	**19.75 ±4.81**	**44.20 ±13.13**	**0.47 ±0.11**	1210
	Sithonia	**18.05 ±2.85**	**27.64 ±4.75**	**0.66 ±0.07**	1019
Pinus radiata	Stratoni	**21.15 ±2.19**	**33.28 ±3.69**	0.64 ±0.05	1015
	Sithonia	**17.25 ±1.74**	**24.70 ±1.83**	0.69 ±0.05	981

Note: Values in bold indicate a significant difference between different areas.

in Stratoni, especially for *Pinus pinaster*. The H:D ratio is higher in Sithonia, especially for *P. radiata*. Therefore, the larger number of trees per hectare is found in Stratoni for *P. pinaster*, while the smaller one is found in Sithonia for *P. radiata* (Table 1).

Chemical composition in needles, litter and soil

Chemical composition of *Pinus pinaster*

Concentrations of most measured nutrients are higher in Stratoni. Specifically, concentrations of i) N, P, Mg, Cu, and Fe in needles, ii) P, Mg, Fe and Mn in litter and iii) P, Ca, K, and Zn in soil at most soil depths have higher values in Stratoni.

Table 2 shows concentrations of nutrients in needles and litter for *P. pinaster* in both areas.

Table 3 shows concentrations of nutrients in soil according to soil depth for *P. pinaster* in both areas.

Chemical composition of *Pinus radiata*

Concentrations of N, P and Zn in needles, Mg, Fe and Zn in litter are higher in Stratoni. Overall, all macronutrient concentrations, but P at shallow soils, are higher in Stratoni, as well as concentrations of Ca, K and Zn at most soil depths.

Table 4 shows concentrations of nutrients in needles and litter for *P. radiata* in both areas.

Similarly Table 5 shows concentrations of nutrients in soil according to soil depth for *P. radiata* in both areas.

Soil chemical properties under *Pinus pinaster* stands

In both study areas the soil was acid (pH 4.02–5.36). Concentrations of most nutrients in soil show higher values in Stratoni, where P, Ca, K, and Zn are in higher concentrations. On the contrary, in Sithonia only Fe is in higher concentrations in soil. The different parent material between the two areas plays an important role. In litter,

Table 2. Nutrients (mean ±s.d.) in needles and litter for *Pinus pinaster* in Stratoni and Sithonia.

Elements	Needles		Litter	
	Stratoni	**Sithonia**	**Stratoni**	**Sithonia**
		Nutrients		
N, %	**1.11 ±0.45**	**0.73 ±0.02**	0.84 ±0.35	0.63 ±0.13
P, mg·g^{-1}	**0.79 ±0.13**	**0.61 ±0.15**	**0.47 ±0.15**	**0.32 ±0.09**
Ca, mg·g^{-1}	3.52 ±1.97	4.75 ±0.59	**4.83 ±0.28**	**6.04 ±0.96**
Mg, mg.g^{-1}	**2.72 ±0.50**	**2.03 ±0.47**	**3.27 ±1.22**	**1.94 ±0.28**
K, mg·g^{-1}	4.85 ±1.19	6.09 ±1.55	1.10 ± 0.34	1.33 ±0.17
		Micronutrients		
Cu, mg·kg^{-1}	**11.29 ±7.4**	**3.63 ±0.9**	24.33 ±8.1	23.26 ±7.6
Fe, mg·kg-^{1}	**962.36 ±353**	**310.44 ±57.1**	**3.071 ±628.0**	**2.070 ±153.8**
Zn, mg·kg-^{1}	38.12 ±9.28	34.79 ±6.91	**298.28 ±66.2**	**744.78 ±187.72**
Mn, mg·kg-^{1}	125.74 ±68.94	168.83 ±61,77	**101.80 ±10.8**	**60.47 ± 8.46**

Note: Values in bold indicate a significant difference between different areas.

Table 3. Nutrients (mean ±s.d.) in soil for *Pinus pinaster* in Stratoni and Sithonia.

Elements	Depth of soil layer							
	0–10 cm		10–20 cm		20–40 cm		40–60 cm	
	Stratoni	Sithonia	Stratoni	Sithonia	Stratoni	Sithonia	Stratoni	Sithonia
				Nutrients				
N, %	**0.22 ±0.07**	**0.13 ±0.07**	0.11 ±0.07	0.11 ±0.06	0.08 ±0.06	0.09 ±0.03	0.06 ±0.05	0.06 ±0.03
P, mg·100g^{-1}	**1.32 ±0.60**	**0.63 ±0.08**	**1.03 ±0.37**	**0.52 ±0.06**	**0.88 ±0.45**	**0.47 ±0.09**	**0.72 ±0.33**	**0.47 ±0.10**
Ca, cmole·kg^{-1}	**5.57 ±3.11**	**1.33 ±0.83**	**4.31 ±2.64**	**1.51 ±1.00**	**3.48 ±2.09**	**1.71 ±0.83**	**4.31 ±3.50**	**1.40 ±0.79**
Mg, cmole·kg^{-1}	**0.42 ±0.19**	**0.19 ±0.12**	0.21 ±0.09	0.15 ±0.08	0.15 ±0.09	0.19 ±0.09	0.11 ±0.05	0.12 ±0.05
K, cmole·kg^{-1}	**12.93 ±5.50**	**3.43 ±3.27**	**8.24 ±5.22**	**2.79 ±3.58**	6.27 ±4.88	3.07 ±1.57	**6.32 ±5.50**	**1.86 ±1.21**
				Micronutrients				
Cu, mg.kg^{-1}	2.18 ±0.99	3.10 ±2.60	2.40 ±1.29	2.75 ±1.61	2.01 ±0.84	4.00 ±2.32	2.03 ±0.78	1.96 ±0.84
Fe, mg·kg^{-1}	**32.14 ±11.14**	**42.55 ±5.47**	30.83 ±12.2	38.80 ±6.2	**26.99 ±0.89**	**39.7 ±7.53**	**23.78 ±6.9**	**34.2 ±4.29**
Zn, mg·kg^{-1}	**11.63 ±4.39**	**3.08 ±0.99**	**4.83 ±1.98**	**1.45 ±0.69**	**3.33 ±1.44**	**1.22 ±0.94**	**2.46 ±1.63**	**0.90 ±0.33**
Mn, mg·kg^{-1}	26.05 ±12.98	24.98 ±6.21	19.15 ±16.2	11.43 ±7.14	17.28 ±15.28	8.29 ±5.72	**13.9 ±12.3**	**6.41 ±5.62**

Note: Values in bold indicate a significant difference between different areas.

Table 4. Nutrients (mean ±s.d.) in needles and litter for *Pinus radiata* in Stratoni and Sithonia.

Elements	Needles		Litter	
	Stratoni	Sithonia	Stratoni	Sithonia
		Nutrients		
N, %	**1.66 ±0.84**	**0.85 ±0.052**	1.04 ±0.35	0.85 ±0.07
P, mg·g-^{1}	**0.97 ±0.11**	**0.58 ±0.03**	0.46 ±0.19	0.46 ±0.19
Ca, mg·g-^{1}	**3.12 ±1.06**	**5.84 ±2.62**	4.63 ±3.15	7.02 ±1.74
Mg, mg·g-^{1}	1.97 ±0.34	2.01 ±0.69	**2.92 ±0.69**	**2.09 ±0.48**
K, mg·g^{-1}	7.63 ±2.77	6.06 ±0.76	1.75 ±1.09	1.09 ±0.18
		Micronutrients		
Cu, mg·kg-^{1}	7.68 ±1.92	8.74 ±3.90	22.17 ±15.23	28.22 ±5.64
Fe, mg·kg-^{1}	1,334 ±1.33	487.05 ±342.14	**3,034 ±588.30**	**2,318 ±465.00**
Zn, mg·kg^{-1}	**84.62 ±65.62**	**30.81 ±10.53**	**140.22 ±90.74**	**57.59 ±10.50**
Mn, mg·kg^{-1}	210.12 ±110.00	253.58 ±120.24	512.14 ±456.48	826.14 ±245.87

Note: Values in bold indicate a significant difference between different areas.

Table 5. Nutrients (mean ±s.d.) in soil for *Pinus radiata* in Stratoni and Sithonia.

Elements	Depth of soil layer							
	0–10 cm		10–20 cm		20–40 cm		40–60 cm	
	Stratoni	Sithonia	Stratoni	Sithonia	Stratoni	Sithonia	Stratoni	Sithonia
				Nutrients				
N, %	**0.26 ±0.93**	**0.09 ±0.03**	0.14 ±0.10	0.08 ±0.01	0.09 ±0.07	0.06 ±0.02	**0.03 ±0.01**	**0.051 ±0.01**
P, mg·100g^{-1}	1.0 ±0.73	0.52 ±0.14	0.84 ±0.70	0.54 ±0.21	0.65 ±0.43	0.46 ±0.07	0.55 ±0.19	0.46 ±0.12
Ca, cmole·kg^{-1}	**3.34 ±2.46**	**1.20 ±0,26**	**2.72 ±2.06**	**1.08 ±0.52**	**2.60 ±1.64**	**1.14 ±0.36**	**3.47 ±1.90**	**0.96 ±0.49**
Mg, cmole·kg^{-1}	**0.33 ±0.08**	**0.20 ±0.08**	0.21 ±0.07	0.17 ±0.09	0.16 ±0.11	0.17 ±0.05	0.17 ±0.13	0.14 ±0.04
K, cmole·kg^{-1}	**9.35 ±6.13**	**2.68 ±1.11**	**6.66 ±4.78**	**2.01 ±1.36**	**5.03 ±3.64**	**1.74 ±0.74**	**6.13 ±3.95**	**1.38 ±0.55**
				Micronutrients				
Cu, mg.kg^{-1}	2.02 ±1.39	2.58 ±1.83	3.04 ±1.88	2.14 ±1.06	3.03 ±1.45	1.75 ±1.04	1,93 ±0.57	1.74 ±0.75
Fe, mg·kg^{-1}	33.14 ±9.32	42.94 ±8.94	32.90 ±8.26	38.61 ±10.22	26.85 ±5.97	28.50 ±10.04	21.04 ±7.05	27.84 ±7.67
Zn, mg·kg^{-1}	**7.66 ±3.75**	**1.70 ±0.80**	**4.47 ±3.62**	**0.95 ±0.30**	3.70 ±5.01	0.73 ±0.35	**4.64 ±3.85**	**0.75 ±0.10**
Mn, mg·kg^{-1}	21.54 ±15.63	16.83 ±8.30	21.83 ±17.62	10.83 ±10.02	20.32 ±19.35	6.66 ±5.97	12.29 ±11.52	4.95 ±4.10

Note: Values in bold indicate a significant difference between different areas.

higher concentrations of P, Mg Fe and Mn were found in Stratoni, while higher concentrations of Ca and Zn were found in Sithonia. Due to better growth of *P. pinaster* in Stratoni, greater amounts of organic residues are produced, so higher nutrients' concentrations in litter are observed. In needles, concentrations of N, P, Mg, Cu and Fe were found in higher concentrations in Stratoni.

Soil chemical properties under *Pinus radiata* stands

In both study areas the soil was also acid (pH 4.02–5.36). Concentrations of macronutrients at shallow soils, concerning extracted cations, also show higher values in Stratoni, where the soil has higher concentrations of N, Ca, Mg, and K. At a greater depth (>10 cm), higher Ca and K content is observed in Stratoni. Higher concentrations of Zn was also found in soil in Stratoni. Higher concentrations of Mg, Fe and Zn in litter and N, P and Zn in needles were found in Stratoni, but only higher concentrations of Ca in needles were found in Sithonia. Concentrations of most nutrients in litter and needles do not show statistically significant differences between the two areas, but there are significant differences in most nutrients between the two areas at shallow soils.

Discussion

Soil in both areas is deep, compared to most pine reforestations in Greece, concerning mainly semi-mountainous, semi-

arid, rather dry, warm areas. Tree dimensions for both conifers are obviously greater in Stratoni, presenting the best tree growth in Halkidiki. The H:D ratio shows greater wind stability in Stratoni for *P. pinaster*, but no differences between the two areas for *P. radiata*.

The amounts of Ca, Mg and K and micronutrients in soil are due to the parent material. Therefore, in Stratoni the greater quantity of Ca in soil is due to limestone rocks, which are common in the study areas. Moreover, greater amounts of Zn in Stratoni or Fe in Sithonia are also due to the parent material and soil impurities.

Higher concentrations of P in litter and soil were found in Stratoni for *Pinus pinaster*. Moreover, concentrations of N only at shallow soils of both conifers showed higher values in Stratoni. For *P. pinaster* the results showed equal or higher concentrations of N, but lower concentrations of P in soil in relation to natural forests in Spain. For *P. radiata*, results showed equal higher concentrations of most nutrients in soil, but lower concentrations of P in litter in relation to *Pinus radiata* plantations in Australia (Turner and Lambert 1988, Knicker et al. 2005, Hopmans and Elms 2009, Martins et al. 2009).

In Stratoni higher concentrations of N, P, Mg, Cu and Fe were found in foliage of *P. pinaster*, as well as higher concentrations of N, P and Zn were found in foliage of *P. radiata*. P and N-absorption by trees is an important growth factor for both coniferous species that seems to be better in Stratoni. Phosphorus and nitrogen concentrations in needles found in Sithonia for both conifers are below the reported marginal level and below the values commonly observed in other *Pinus pinaster* and *Pinus radiata* stands that are known to be nutrient limited. However, phosphorus concentrations in needles found in Stratoni for *P. radiata* were also below the critical levels according to the literature (Will 1985, Zas 2003, Zas and Serrada 2003, Warren et al. 2005, Martins et al. 2009).

The results show low phosphorus content in soil of both areas, mainly in Sithonia, that is an aggravating factor for the growth of both conifers.

Conclusions

All measured dendrometric variables for both conifers are greater in Stratoni. Comparing the two areas, the highest nutrient content in soil, litter and needles for both conifers was found in Stratoni. The greatest differences were observed at shallow soils (0–10 cm) for most nutrients. Consequently, Stratoni seems to be more suitable area for both conifers and this is clearer for *Pinus pinaster*. The phosphorus content in litter, foliage and soil at all depths is higher in Stratoni for *Pinus pinaster*, however, there is a phosphorus deficit concerning both areas. The results show that nutrient content in litter, soil and foliage found mainly in Stratoni, does not appear to be prohibitive for both conifers, but certainly, given a lack of phosphorus, has nothing to do with data from high-productivity forests. The results contribute to the planning of appropriate forest management for both areas, considering the prospect of preserving or replacing both conifer species.

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