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Soil fertility and productivity estimation of *Pinus pinaster* Aiton reforestations in Central and Northeast Chalcidice in Northern Greece

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Abstract

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Maritime pine (*Pinus pinaster* Aiton) is a notable fast-growing conifer, native to the Western Mediterranean Basin, which is considered suitable for reforestations. This tree species was artificially installed in Chalcidice, Northern Greece, about 40 years ago, in order to upgrade mountain ecosystems. The experiment reported in this paper was undertaken to estimate soil conditions and the development progress of maritime pine in the above reforestations. Samples of mineral soil and forest floor were taken from 12 different sites at 2 locations. Despite age, rather weak maritime pine trees are found in both studied locations. Furthermore, significant accumulation of organic matter and nutrients was observed in both forest floor and mineral soil.

Keywords: degraded ecosystems; conifer; native vegetation; accumulation of nutrients; forest floor; mineral soil

There is a constant great shortage of wood products in Greece, like in other Mediterranean countries. However quantities of wood products coming from Greek forests have increased significantly nowadays, due to reforestations, using mainly coniferous species. Maritime pine is a notable fast-growing conifer, native to the Western Mediterranean Basin, presenting a distribution over than 4 million ha (Alía et al. 1997; Correia et al. 2008). This tree species was artificially installed in several locations of Northern Greece from 1920 to 1970 (Varelides, Kritikos 1994) in order to improve degraded ecosystems.

Soil fertility is able to modify key processes, controlling the growth of plants in forest ecosystems. Soil fertility also includes the nutrients of forest floor in forest ecosystems. The aim of this study is to evaluate soil conditions, in a relationship with dendrometric variables of maritime pine reforestations in Central and Northeast Chalcidice. The results could be taken into account for the best management practices in the years to come.

MATERIAL AND METHODS

Study area. The study area is located at Polygyros and Gomati, in Central and Northeast Chalcidice in Northern Greece (Fig. 1). The distance between them is about 41 km. Polygyros is a more highland

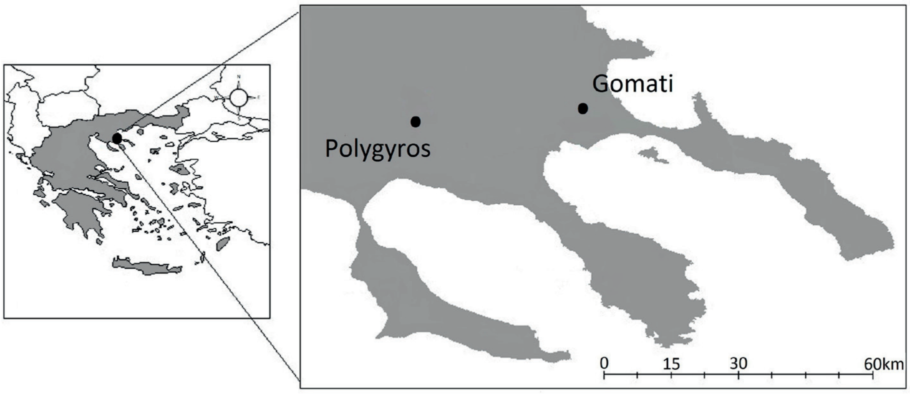

Fig. 1 The study area

location, because it is situated near mountains and decidedly further from the sea. Maritime pine reforestations were carried out there almost 40 years ago. The forest soil has formed on gneiss parent material. Conifers coming from reforestations cover about 918 ha in Chalcidice (The Greek Biotope/Wetland Centre 1996). Native vegetation is dominated by oaks, or evergreen shrubs such as downy oak (*Quercus pubescens* Willdenow), Italian oak (*Quercus frainetto* Tenore), kermes oak (*Quercus coccifera* Linnaeus), holm oak (*Quercus ilex* Linnaeus), tree heath (*Erica arborea* Linnaeus), strawberry tree (*Arbutus unedo* Linnaeus), Greek strawberry tree (*Arbutus andrachne* Linnaeus), rock rose (*Cistus* sp.), mastic tree (*Pistacia lentiscus* Linnaeus) and green olive tree (*Phillyrea latifolia* Linnaeus).

The climate is mainly temperate and mild, but is locally influenced by the presence of hills and mountains. Rainfalls are frequent; therefore a dry period of 1.5–2.5 months is presented. Average annual precipitation is 794.4 mm, mean annual temperature is 9.85°C and daily mean temperature ranges from 2.1 to 21.6°C. Climate is characterized wetter in Polygyros, due to proximity to mountains.

Supporting the reforestations, native vegetation was completely removed. Furthermore, tillage and terrace construction occurred before reforestations in order to decrease steep slopes (Chatzistathis, Dafis 1989). Each soil step had a width of about 3.5 m and a height of about 60 cm. Tree planting was done along soil terraces in two rows; in the first row about 2.5 m from the slope, better soil conditions were formed due to a greater soil depth.

Sampling plot description. For this survey 12 sampling plots were chosen, each covering 314 m^2. All sampling plots were located within a pure and undisturbed maritime pine plantation. Sampling plots from Polygyros were located at 23°25'678''E latitude and 40°23'072''N longitude, while sampling plots from Gomati are located at 23°44'678''E latitude and 40°23'104''N longitude. The average slope is 25%, while the dominant aspect is oriented northwest. The elevation of sampling plots ranges from 275 to 586 m a.s.l. For each location 6 sampling plots were selected, 3 in medium site quality stands and 3 in bad site quality stands. In each sampling plot the number of maritime pine trees was counted, while their heights and breast height diameters were also measured.

The site quality classification system reflects the efficiency of forest lands, ranges from the best to the worst. Site quality is defined as the ability of a land to support the growth of trees (Spurr 1952). In the study area the classification of sampling plots was based on forest and soil characteristics, according to the Greek Forestry Services.

Soil samples. A square metallic frame 25 × 25 cm was used for the sampling of forest floor. Forest floor 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 forest floor within the square area was transferred into labelled plastic bags. About one hundred and twenty forest floor samples were transported to the Forest Soil Laboratory of Aristotle University. After drying in an oven at 74°C for 48 h, all forest floor samples were weighed, ground and prepared for analyses.

Soil samples were taken from soil depths of 0–10, 10–20 20–40 and 40–60 cm, from two different soil profiles per sampling plot. About ninety soil samples were transferred into labelled plastic bags and transported to the laboratory. Then all soil samples were air-dried, weighed, ground, passed through a 2-mm sieve and prepared for analyses.

Experimental analyses. Chemical analyses of forest floor were performed in pulverized and homogenized material. Organic matter was determined using the loss-on-ignition method. Forest floor samples were dried at 515°C for 4.5 h. Total N was estimated using the Kjeldahl digestion method (Stevenson 1982). The nutrients Ca, Mg, K, Fe, Mn, Zn and Cu were determined 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 texture was determined using the Bouyoucos hydrometer method (Bouyoucos 1962). Soil pH was determined using a pH meter (Crison, Spain) (McLean 1982). Extractable P was also measured using the blue of ammonium sulphoparamolybdate method (Olsen, Sommers 1982). Exchangeable cations such as Ca, Mg, and K were determined using the CH_3COONH_4 1N solution of pH 7 (Thomas 1982). The micronutrients Fe, Mn, Zn and Cu were determined using the diethylenetriaminepentaacetic acid solution of pH 7.3 (Lindsay, Norvell 1978). All extracted cations Ca, Mg, K, Fe, Mn, Zn and Cu were measured using an atomic absorption spectrophotometer.

All nutrient concentrations were changed into quantities, measured in $t \cdot ha^{-1}$ or $kg \cdot ha^{-1}$, using bulk density at a given soil depth. Similar estimations were carried out for several Greek forest species, such as *Q. frainetto* (Alifragis 1984), *Pinus nigra* J.F. Arnold (Tsiontsis 1991; Ganatsas 1993), *Fagus* sp. (Ganatsas 1993; Ganatsas, Papaioannou 1997) and *Abies* sp. (Tantos 1997).

Statistical analysis. All statistical analyses were performed using the SPSS statistics software (Version 17, 2009). Specifically the *t*-test was used to assess the significance of differences between amounts of organic matter and nutrients from different locations or site quality stands (Howitt, Cramer 2001).

RESULTS

Dendrometric variables for the study area

Tables 1 and 2 show the dendrometric variables on sampling plots, including average height, average diameter and density.

Comparing the studied locations, no substantial differences were noticed in density and dimensions of trees (Tables 1 and 2). Obviously, higher values were presented in the medium site quality stands in most variables. However it seems that smaller, but numerous pine trees are able to survive in the poorest soil conditions, probably because the competition of native vegetation is not very intense.

Table 1. Dendrometric variables for both locations

Location	Height (m)	DBH (cm)	Number of trees per hectare
Polygyros	8.725	18.435	1,688
Gomati	8.35	17.22	1,942

Table 2. Dendrometric variables for both site quality stands

Site quality stand	Height (m)	DBH (cm)	Number of trees per hectare
Medium	11.125	18.355	1,814
Bad	8.09	16.73	2,102

Chemical composition of forest floor and mineral soil

Table 3 shows the accumulation of nutrients in forest floor and mineral soil in both studied locations.

Chemical composition of forest floor

The accumulation of organic matter, N, K and Zn in the forest floor at Polygyros shows significant differences between different site quality stands. The accumulation of organic matter and N in the forest floor of Gomati indicates significant differences between different site quality stands. Overall, the accumulation of all nutrients is rather greater in the medium site quality stands, likewise in the forest floor of Gomati.

Physical and chemical soil properties

In both studied locations there are acid forest soils (pH 4.7–5.9), moderate soil texture between loamy sand and sandy clay loam. The soil texture shows no appreciable differences between different site quality stands. Soil depth is between shallow and moderate and ranges from 30 to 70 cm. However, most soil profiles are usually about 60 cm in thickness in the study area.

The accumulation of calcium and magnesium in the mineral soil of Polygyros reveals statistically significant differences between medium and bad site quality stands. Most nutrients have a tendency of increased amounts in the medium site quality stands.

The accumulation of calcium in the mineral soil of Gomati shows statistically significant differences between medium and bad site quality stands. The amounts of practically all soil nutrients do not present any significant differences between medium and bad site quality stands.

Table 3. Organic matter and nutrients (mean value and standard deviation) of the forest floor and mineral soil at Polygyros and Gomati

Location	Forest floor				Mineral Soil			
	Polygyros		Gomati		Polygyros		Gomati	
Site quality	medium (III)	bad (IV–V)	medium (III)	bad (IV–V)	medium (III)	bad (IV–V)	medium (III)	bad (IV–V)
Organic matter ($t \cdot ha^{-1}$)	**30.84 ± 3.06**	**17.33 ± 2.63**	**32.68 ± 2.90**	**21.97 ± 2.53**	123.13 ± 27.99	128.36 ± 56.79	167.67 ± 119.89	181.89 ± 34.06
Nutrients ($kg \cdot ha^{-1}$)								
N	**478.64 ± 24.62**	**355.1 ± 15.02**	**635.35 ± 25.28**	**462.47 ± 19.92**	4,144.27 ± 620.65	4,679.78 ± 437.28	4,016.17 ± 919.79	5,419.98 ± 1,723.55
P	28.13 ± 4.31	21.44 ± 1.39	31.46 ± 4.29	23.43 ± 2.85	35.34 ± 2.65	31.90 ± 5.04	35.60 ± 3.18	34.61 ± 2.45
Ca	346.47 ± 125.85	236.31 ± 94.10	375.82 ± 64.58	217.59 ± 48.65	**9,350.42 ± 330.09**	**4,969.21 ± 156.01**	**3,936.09 ± 265.07**	**4,820.46 ± 127.01**
Mg	135.90 ± 24.57	131.49 ± 38.17	231.30 ± 54.03	190.87 ± 102.56	**2,288.08 ± 176.61**	**527.79 ± 76.01**	1,802.12 ± 808.9	1,212.79 ± 113.85
K	**123.19 ± 16.31**	**84.23 ± 14.85**	178.47 ± 65.86	120.18 ± 35.58	336.31 ± 98.26	290.94 ± 63.78	428.22 ± 127.70	514.07 ± 113.49
Cu	0.68 ± 0.21	0.55 ± 0.09	6.42 ± 10.13	1.45 ± 0.60	2.13 ± 0.79	1.23 ± 0.37	1.72 ± 1.64	3.16 ± 1.40
Fe	22.53 ± 11.41	12.58 ± 2.06	84.70 ± 56.30	35.08 ± 12.38	108.46 ± 38.90	87.64 ± 30.17	183.06 ± 50.74	157.04 ± 26.72
Zn	**3.43 ± 0.49**	**2.59 ± 0.13**	4.61 ± 2.74	4.16 ± 0.89	3.08 ± 1.02	3.76 ± 1.12	4.83 ± 1.81	6.21 ± 1.90
Mn	33.55 ± 8.23	21.86 ± 5.15	72.52 ± 73.01	54.24 ± 29.73	80.50 ± 20.42	76.27 ± 17.30	85.02 ± 95.36	103.81 ± 46.75

Values in bold indicate a significant difference between different site quality stands

DISCUSSION

Maritime pine trees have only small dimensions, even in better quality stands, in both studied locations. Despite age, the upper height ranged from 10 to 13 m (rarely 15 m), while the upper height of this species may be almost 30 m (Athanasiadis 1986). Furthermore, most pine trees seem abnormally formed. Twisted trunks, too many branches and drought are occasionally observed in several points of the crown, especially in the bad site quality stands. It is also clear that maritime pine installation frequently failed, as young plants were not able to survive, while the most adapted native vegetation steadily increased.

The forest floor often represents one of the most useful elements for the changes in a disturbed natural forest ecosystem nowadays (Prats et al. 1991). A great accumulation of nutrients is noticed in the forest floor in the best site quality stands, especially at Gomati. The accumulation of mineral soil nutrients does not seem to be influenced by site quality. Variations of soil nutrients in the mineral layer are not often in relation with those of the similar forest floor for both studied locations. The quantities of soil nutrients depend on climatic parameters; the annual amount and distribution of rainfalls are the most important factors (Papaioannou 2013).

The procedure influencing the vertical distribution of nutrients in forest soils includes weathering of rocks, atmospheric deposition, infiltration and organic recycling (Kirby 1985; Trudgill 1988). Great amounts of soil calcium and magnesium are present in both studied locations, especially at Polygyros. On the one hand, increased calcium is considered undesirable for the development of maritime pine; it prevents the potassium uptake by plants. On the other hand, that point of view has raised objections (Gogos 1978).

Moreover, the amount of phosphorus is rather insufficient for the needs of maritime pine in both studied locations. There is often a phosphorus deficiency in maritime pine forests, so that soil lubrication is suggested during the first years of planting (Ali et al. 2014). However, the previous procedure was completely impracticable in the study area. Comparing maritime pine with other studied Greek conifers (Tsiontsis 1991; Ganatsas 1993; Tantos 1997) the amount of soil phosphorus in the study area is also reduced.

Finally, comparing both locations, the amounts of soil nutrients (especially micronutrients) seem greater at Gomati in most cases, because this location is characterized by the significant presence of metals.

CONCLUSIONS

The growth of maritime pine plantation was not such as it was expected to be. On the contrary, low productivity forests were created, while native vegetation has returned progressively. Despite of a wide adaptability in a variety of soils and climates, maritime pine seems to be rather ineffective in the study area.

Forest floor constitutes a reserve of nutrients. In the study area the rate of forest floor decomposition is considered rather slow, so that nutrients cannot adequately enrich the mineral soil.

Great amounts of soil calcium and magnesium are present in the study area. These amounts, especially in the medium quality sites in the mineral soil of Polygyros, may be attributed to either impurity of the parent material or soil movements from the higher stands, since the presence of limestone rocks is common. The amounts of phosphorus are rather reduced for the needs of maritime pine in both studied locations.

In conclusion, it is evident that the correct management practices have not been carried out, at the expense of natural regeneration, as well as the decomposition of forest floor is rather incomplete. In order to realize the correct management project in the study area, soil characteristics constitute an important parameter.

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