Resin production in natural Aleppo pine stands in northern Evia, Greece

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We investigated the variability in resin yield of Aleppo pines in Evia (Greece) with the aim to exploit this natural resource in a sustainable way. Ten experimental plots were established in natural pine stands for monitoring. Our results revealed significant differences among stands, with high variation among individual trees in each plot. Maximum resin production was achieved in the Livadakia site whereas the minimum was obtained in Kokinomilia. All trees were classified according to their resin production into five classes ranging from not economically profitable (I) to highly profitable (V). From a total of 2483 trees, 1043 (42%) were in class I whereas the remaining 58% was classified into economically acceptable classes (II–V). A weak correlation (R^2 = 0.315) between resin production and tree size was found suggesting that taller trees produced more resin than smaller trees.

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Resin tapping (Fig. 1) is a forest activity which has been an integral part of forest management in Evia and other important Aleppo pine *Pinus halepensis* forests in Greece (Eleftheriadis 1987, Galanos 1987, Kapralos 1987, Papajiannopoulos 1997, Spanos et al. 2002). However, during the last 20–30 years annual production has dropped dramatically due to socio-economic causes. Thus, while in 1965 annual resin production in Greece was around 12 000 tons, in 1995 it dropped to less than 6000 tons and today it is in the range of 4000–5000 tons (Papajiannopoulos 1997, Karaoglanoglou and Koukios 2002). The area of pine forests available for resin tapping is about 327 500 ha, whereas the area actually used is 147 500 ha. Resin tapping is mainly practiced in the Evia, Korinthia, Ilia, Attica and Chalkidiki regions and in the last decade engaged below 2000 workers (Papajiannopoulos 1997, Karaoglanoglou and Koukios 2002). Resin extraction is performed by tapping alive trees with the 'debarking' (bark-peeling) method, where a slice of the bark (about 1.5 × 8–10 cm in size) is removed without wounding the actual wood, using a stimulant paste (a mixture of sulfuric acid, water and kaolin) to increase resin flow. The most important products of pine resin are turpentine and rosin (colophony), which are used in chemical industry for several purposes (Philippou 1986, Karaoglanoglou and Koukios 2002, Papajiannopoulos 2002, Spanos et al. 2002).

Resin tapping normally takes place every 10–15 days between April and October (i.e. the growth season), and is mainly applied on Aleppo pines with a diameter at breast height (DBH) over 25 cm. Only one tapping area is normally allowed at this diameter. Two tapping areas are possible if DBH is ≥ 32 cm, and the horizontal distance between them should be at least 7 cm. The width of each tapping face (the resin flow area) may vary from 8 to14 cm, depending upon diameter. Resin collectors usually open wounds that are 11–12 cm wide. Each tapping area

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Figure 1. Resin tapping of *Pinus halepensis* in northern Evia, Greece.

is extended upwards, reaching mean heights of 2.0–2.2 m above ground. The tapping area may be higher up in cases justified by resin yield (but usually not recommended when other trees are available; Papajiannopoulos 2002). Several factors influencing resin production (through wounding) have been reported (Zanski 1970, Moulalis 1981, Philippou 1986, Papajiannopoulos 1997, 2002), such as soil, climate, applied chemicals, tree age, silvicultural regime, and genetics of trees. Managing the genetic diversity of forest species is an essential component of forest management practices (Namkoong 1991, Eriksson et al. 1995, Andersson et al. 1997, Buchert et al. 1997, Mullin and Bertrand 1998, Spanos and Feest 2007) since it 1) secures the provision of goods of ecological and economical value, 2) preserves the capacity of forests to respond to changing environmental pressures, and 3) is a tool to keep the genetic material of forest trees for breeding purposes and further use. The purpose of this study was 1) to address the variability in resin production in natural pine forests in northern Evia, 2) to investigate the correlation between tree size and resin production, and 3) to draw conclusions for sustainable forest management.

Methods

In 2001, ten experimental plots (Table 1) were identified and selected in northern Evia (Fig. 2) in the framework of the TWIG (Transnational Woodland Industries Group) European Programme. In 2005, at each experimental plot 195 to 300 trees (except in Kalamoudi, where 109 trees were recorded), 30–60 years old with DBH ≥ 30 cm were

Table 1. Experimental plots (sites) selected for the study of resin production in northern Evia.

Plot no. Study area	No. of trees	Latitude	Longitude	Altitude (m)	Aspect	Slope (inclin.)	Geology (bedrock)
1. Livadakia	233	38°46′20″	23°34′16″	220	E/NE	moderate	peridotite
2. Prokopi	300	38°44′24″	23°29′21″	230	E/NE	moderate	peridotite
3. Kalamoudi	109	38°49′47″	23°18′17″	280	SE	moderate	tertiary deposits
4. Tsapournia	300	38°57′56″	23°17′51″	220	NE	moderate	tertiary deposits
5. Marouli	195	38°52′45″	23°14′29″	320	N/NE	gently/ moderate	tertiary deposits
6. Kokinomilia	250	38°53′46″	23°14′57″	550	W/NW	moderate	tertiary deposits
7. Papades	300	38°55′45″	23°21′49″	340	S/SE	gently/ moderate	tertiary deposits
8. Krioneritis	271	38°56′32″	23°16′22″	380	SW	moderate	tertiary deposits
9. Krioneritis	250	38°55′41″	23°16′20″	550	SW	moderate	tertiary deposits
10. Pikanaria	275	38°50′59″	22°57′39″	320	N/NE	moderate	hard limestone

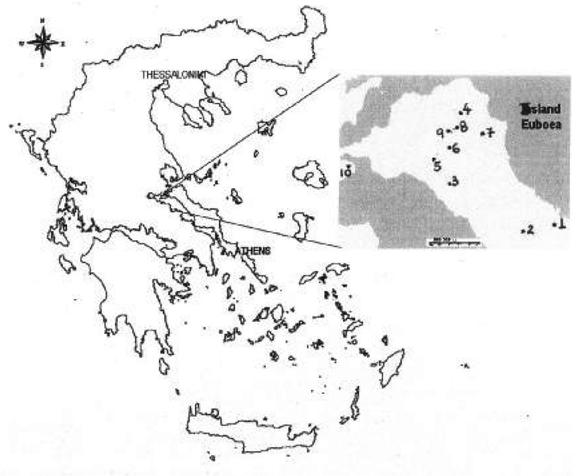

Figure 2. Geographical distribution of experimental plots in northern Evia, Greece.

randomly selected. All trees were marked and labeled. Most trees had one active (current) tapping area. In cases where two active tapping areas were used, the average production was multiplied by 1.43 to calculate the annual tree production (kg tree^{-1} area^{-1} year^{-1}) (Papajiannopoulos 1983). All other techniques (size of bark cuttings, height of tapping face, paste application, shifting period, etc.) were the standard techniques applied in northern Evia, as regulated by the forest law (Papajiannopoulos et al. 1995, Papajiannopoulos 1997, 2002) (Fig. 1). The tapping period started in April 2005 and ended in November 2005. Resin production at the end of the growing season was recorded in all trees by weighting (with 10 g accuracy) the amount of resin collected in appropriate plastic bags. Based on the minimum annual resin production per tree (2.70 kg tapping area^{-1} tree^{-1} year^{-1}) considered as economically profitable in northern Greece (Chalkidiki Peninsula; Papajiannopoulos 1997, 2002), all trees were classified into five classes of resin production (Table 2).

Table 2. Classification of experimental trees into five resin-production classes.

Resin production class	Resin yield tapping area^{-1} tree^{-1} (kg)	Economically profitable
I	0.50–2.70	no
II	2.71–5.40	yes
III	5.41–8.10	yes
IV	8.11–10.80	yes
V	10.81–13.50	yes

In Marouli (plot no. 5) a more detailed study was carried out; resin production, diameter at breast height (DBH), height (2 classes), crown form (3 classes), stem form (3 classes) and number of tapping areas per tree were recorded for each individual tree. Trees were classified as follows:

Height classes (Fig. 3a): class H-I = tall trees growing in the overstorey, and class H-II = smaller trees growing underneath.

Crown form (Fig. 3b): class CF-I = trees with narrow crown (branches covering 2/3 of the stem), class CF-II = trees with relatively open crown (branches covering 1/2 of the stem), and class CF-III = trees with open crown (branches covering 1/3 of the stem).

Stem form (Fig. 3c): class SF-I = trees with relatively straight stem, class SF-II = trees with moderately curved stem, and class SF-III = trees with curved stem.

Statistical analysis was carried out using ANOVA and regression analysis. The linear model followed for the analysis of variance (ANOVA) was $Yij = \mu + \alpha i + \varepsilon ij$, where μ is the overall mean, αi is the site effect (I = 0, 1, 2,......10) with (N, σ^2), and εij is the independent random errors having the normal distribution (N, σ^2) (αi values are independent of εij) (Kassab 1989).

In the Marouli plot, similar linear models were used for Height class (Fig. 3b), Crown form (Fig. 3b), and Stem

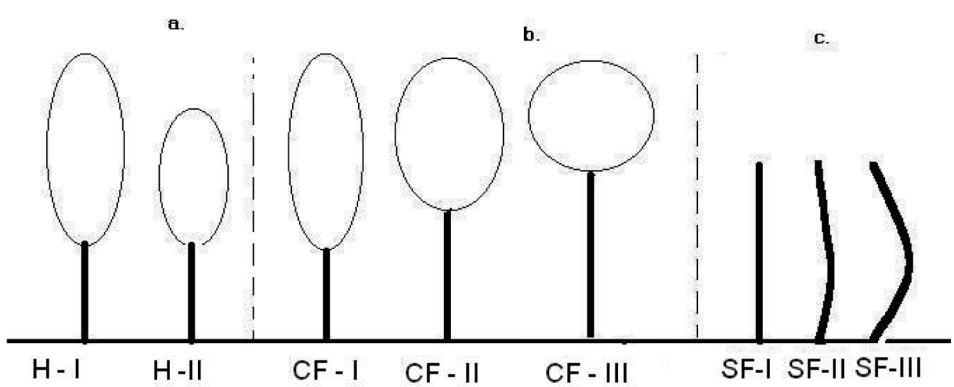

Figure 3. Classification of trees into (a) height, (b) crown form and (c) stem form classes.

Table 3. Statistics (ANOVA) of resin production in the experimental sites.

Source of variance	DF	SS	MS	F value	p
Site	9	3102.568	344.730	162.189	0.0001
Plot	2473	5256.323	2.125		
Total	2482	8358.891			

form (Fig. 3c). Regression analysis performed for the data obtained in the Marouli site was based on the annual resin production per tree and the corresponding DBH.

Results

The results of resin production for the different experimental plots are presented in Table 3 and 4. The ANOVAs showed significant differences ($p < 0.01$) among experimental plots (Table 3). Maximum resin production was recorded in the Livadakia plot (mean 5.9 kg $tree^{-1}$ $year^{-1}$) and the minimum in the Kokinomilia plot (2.3 kg $tree^{-1}$ $year^{-1}$; Table 4). High variation was also recorded among individual trees within the experimental plot (CV range 27.3–53.8%), with resin production ranging 0.5–12 kg $tree^{-1}$ $year^{-1}$ (Table 4).

Out of 2483 monitored trees, 1043 (42%) were classified in class I or not economically profitable, whereas the remaining trees (58%) were economically profitable (Table 4). A considerable number of trees (1074 or 43.2%) were classified into class II, whereas less trees were found in the higher-yield classes (class III, 313 trees or 12.61%; class IV, 50 trees or 2.02%; class V, 3 trees or 0.12%). The distribution pattern of resin production differed among experimental plots. For example, in the case of the Livadakia site most trees (about 53%) were classified into class III, whereas trees classified into class III were notably less in

Table 4. Mean resin production and classification of experimental trees into five resin production classes. Production of class I–V is given in kg within brackets. [a]CV = coefficient of variation, [b]no. of trees, [c]percentage of recorded trees.

Exp. plot	No. of trees	X ± SD	CV (%)[a]	I (0.50–2.70)	II (2.71–5.40)	III (5.41–8.10)	IV (8.11–10.80)	V (10.81–13.50)
(1)	233	5.9 ± 1.6	27.3	6[b] (2.6)[c]	82 (35.2)	124 (53.2)	20 (8.6)	1 (0.4)
(2)	300	2.9 ± 1.4	50.1	154 (51.3)	129 (43.0)	15 (5.0)	2 (0.6)	0 (0.0)
(3)	109	2.4 ± 1.3	53.8	72 (66.0)	34 (31.2)	3 (2.7)	0 (0.0)	0 (0.0)
(4)	300	3.4 ± 1.2	34.5	103 (34.3)	182 (60.7)	15 (5.0)	0 (0.0)	0 (0.0)
(5)	195	4.1 ± 1.8	43.5	41 (21.0)	112 (57.4)	36 (18.5)	6 (3.1)	0 (0.0)
(6)	250	2.3 ± 0.9	39.8	175 (70.0)	75 (30.0)	0 (0.0)	0 (0.0)	0 (0.0)
(7)	300	2.4 ± 1.0	41.6	201 (67.0)	96 (32.0)	3 (1.0)	0 (0.0)	0 (0.0)
(8)	271	4.9 ± 2.1	43.0	43 (15.8)	132 (48,7)	76 (28.0)	18 (6.6)	2 (0.7)
(9)	250	3.8 ± 1.6	42.5	67 (26.8)	146 (58.4)	33 (13.2)	4 (1.6)	0 (0.0)
(10)	275	2.6 ± 1.3	47.8	181 (65.8)	86 (31.3)	8 (2.92)	0 (0.0)	0 (0.0)
Total	2483 (100%)			1043 (42.0%)	1074 (43.2%)	313 (12.6%)	50 (2.0%)	3 (0.1%)

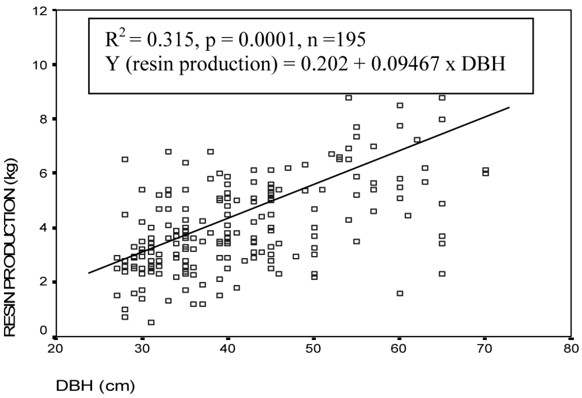

Figure 4. Linear regression of resin production (kg) and tree size expressed as DBH (cm).

other plots (Table 4). For the yield class IV, a considerable number of trees (20 and 18, respectively) were recorded in the Livadakia and Krioneritis plots. But very few trees were classified into the highest yield class (V) in all areas.

The linear regression model constructed from resin production and DBH data (Fig. 4) recorded in the Marouli experimental site was:

Resin production (kg) = 0.202 + 0.09467 × DBH (cm) (r^2 = 0.315, p = 0.0001).

Discussion

Resin production classes

Our results showed significant differences in resin production plots. Most trees were classified into resin yield classes I and II. For higher yield classes III and IV, still a considerable number of trees was recorded, but very few trees were found in class V. Selection of trees could be performed among the highly productive classes for genetic improvement programs, but relatedness among individuals within the same plot should be avoided, and thus genotyping using molecular markers should be performed prior to their introduction into a breeding programme. Given that the genotype × environment interaction affects resin production, multi-environmental experimentation in production areas is needed before genetic material can be used in breeding programs, aimed to increase resin production. Additionally, productivity can be increased by removing trees of less productive classes I and II (Papajiannopoulos 1997, Papajiannopoulos 2002, Spanos et al. 2002).

Resin production and tree size and form

In the Marouli plot (no. 5) results showed relatively low correlation (R^2 = 0.315) between resin production and DBH, but the regression was highly significant. Therefore, the linear regression model obtained could be applied by forest managers to estimate (however broadly) resin production in this area based on DBH. As the model was not validated across all experimental plots in northern Evia, it could not be applied everywhere. A trend to increase ($p > 0.05$) resin production was recorded in trees with relatively open crowns (results not shown), suggesting that photosynthetic and other physiological processes affect resin accumulation (Papajiannopoulos 2002).

Genetic improvement possibilities

Large differences were also found in similar studies among individual trees in the same stand. Other reports (Squillace and Bengtson 1961, Moulalis 1981, Philippou 1986, Ditoras 1987, Papajiannopoulos 2002) pointed out that this intra-population variability is genetically controlled. The heritability coefficient have been reported to be high (h = 0.45–0.90 for *Pinus elliotti*; Squillace and Bengtson 1961, Panetsos 1986, Ditoras 1987) and this variability in resin yield provides the basis for selection and genetic improvement.

In conclusion, this field study shows that there is a large variation in resin production among different populations and also among individual trees in the same-stand population, providing large possibilities for genetic improvement of natural Aleppo pine stands, which directly affects the income of resin producers. We also show a weak correlation between resin production and tree size.

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