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Study of Wood Productivity of Stone Pine (Pinus pinea L.) on Green Rocks in Northwest Syria

Abdulrazaq Alhamoud[1], Amin Alhasan[2], Awad Aljdi[3]

[1,2]Syria/ Idleb University/ Faculty of Agriculture/ Dep. of Renewable natural resources and Ecology

[3]Germany/ University of Giessen

Corresponding Author: Abdulrazaq Alhamoud

E-mail: a.alhammoud@yahoo.com, amin.Mahmoud.alhasan@idlib-university.com, dr.awadjassem@gmail.com

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Abstract

This study was conducted at Al-Sheikh Sayah site (Khirbat Al-Jawz) with the aim of calculating the wood productivity of stone pine (Pinus pinea L.) growing on green rocks (Gabbro). The results showed that the average number of trees per hectare was 285 trees/ha, the average diameter for the site was 16.5 cm, the average height of the trees was 6.2 m, the average form factor was 0.86, the average basal area was 6.27 m2/ha, the average wood stock was 34.6 m3/ha, and the average annual growth was 1.38 m3/ha/year, which is significantly smaller compared to the annual growth rate of stone pine, which ranges from 4 to 10 m3/ha/year. The average wood stock was also lower compared to similar previous studies, which could be attributed to the poor soil conditions on top of the Gabbro rocks and their hard and impermeable physical structure, as well as the uncontrolled cutting of trees due to inadequate protection. Plant surveys indicated that the prevailing natural forest in the area is Pinus brutia, which also grows on green rocks, along with accompanying species such as Quercus cerris subsp. Pseudocerris, Quercus infectoria subsp. microphylla, Ptosimopapus bracteatus, and Alyssum crenulatum.

Keywords: Stone Pine, Wood Stock, Sheikh Sayah, Green Rocks, Northwest Syria.

Introduction

The stone pine (*Pinus pinea* L.) is widely distributed throughout the Mediterranean Basin, especially in the coastal regions of southwestern Europe. It thrives in a wide range of climatic and soil conditions, although it exhibits low genetic diversity. It tolerates shade during the early stages of growth and prefers acidic soil while being tolerant of calcareous soil. The main economic products obtained from this pine tree are its wood products, edible seeds, and stabilization of sandy dunes in coastal areas (Viñas *et al.*, 2016). It can play an economic role by increasing the income of rural forest dwellers based on its primary and secondary products (Küçüker & Baskent, 2017). Stone pine forests are also used for recreational activities, biodiversity conservation, soil erosion control, and carbon stabilizing. These pine trees are among the ecosystems most vulnerable to climate change, and the current increase in drought intensity in the Mediterranean Basin has a negative long-term impact on its forests (Mechergui *et al*., 2021).

Pinus pinea L. is considered a major introduced forestry species in Syria, used for artificial afforestation, unlike other pine species such as (*Pinus halepensis*) and (*Pinus brutia*), which grow naturally in Syria. However, stone pine has occupied vast areas due to artificial afforestation for environmental and productive purposes. It is an ecologically flexible species, adaptable to light and heat, and prefers humid and semi-humid warm bioclimatic belts. It is more affected by the physical properties of the soil than the chemical properties, with a concern for soils rich in active lime. It grows with difficulty in heavy loamy or compacted marly soils, but it tolerates dry and quarried lands. The average wood productivity of stone pine is around 3-4 m3/ha/year, but it can reach up to 10 m3/ha/year in favorable environments (Al-Baghdadi, 2006), such as areas with an annual precipitation above 1000 mm (Ibrahim, 2010). However, its productivity decreases in the Syrian coast within the temperate Mediterranean vegetation zone to 5.38 m3/ha/year with a density of 352 trees/ha in the Jableh pine site (Latakia). This occurs at the age of 40-43 years (Ali, 2004).

The important environmental and productive characteristics of stone pine have led to its wide adoption in artificial afforestation projects in Syria. However, most of these projects have not been studied or evaluated adequately to determine their success and identify existing errors for future avoidance.

Research Aim:

This research aims to determine the annual growth of stone pine planted on green rocks in northwestern Syria through the following:

2.1. Inventory of the forest stand comprising the afforested area and conducting silvicultural measurements.

- Estimation of growth and productivity of stone pine trees at the site to provide recommendations and suggestions that can contribute to the proper management and optimal growth guidance of the site.

Materials and Methods

Study Site:

The study was conducted at the Sheik Sayah afforestation site, administratively belonging to the Bdama village in the Jisr al-Shughur city, with an elevation of 450 meters above sea level. The site is surrounded by Khirbet al-Jawz village to the south (4 km) and Baksariya village to the south (7 km). To the east is the village of Armala (5 km), and to the northeast is the village of Al-Zawf (10 km).

The soil in the area is formed by the weathering of Gabbro rocks and is characterized by a high exchangeable magnesium content in the admixture complex and a low exchangeable calcium content relative to magnesium. The Mg^{++}/Ca^{++} ratio is always greater than one, ranging between 1.87 and 3.54. The soil is relatively thin, ranging from 15 to 40 cm in thickness, which hampers the infiltration of rainfall water into plant roots. Additionally, the low permeability of the parent rock and its poor water-holding capacity contribute to the dryness of these soil types despite the relatively high amount of rainfall in the region.

Figure 1 shows a satellite image of the study site, which has been afforested for over 25 years. The topographic characteristics of the site are described in Table 1.

Figure (1) shows satellite images of the studied site.

Table (1) presents the topographic characteristics of the studied site.

City and Distance from it	Longitude	Latitude	Surrounding Villages	Elevation above Sea Level (m)	Exposure
Khirbet al-Jawz: 7 km	35.9361546	36.1955859	Khirbet al-Jawz - Al-Zawf - Armala	450	South

Accompanying Species:

The accompanying species for Stone Pine was inventoried throughout the site, and plant samples were classified based on available floras: the Syrian and Lebanese Flora by Mouterde (1966, 1970, 1983), the Flora of Turkey by Davis (1965, 1985), numerous master's and doctoral theses, in addition to various online resources. The site originally was a Brutia Pine forest, and the presence of Stone Pine resulted from afforestation efforts following wildfires in the late 1990s. Alongside Stone Pine, which is artificially afforested, and natural brutia pine several ecologically significant species are found, typically associated with green rocks, including:

- *Quercus cerris* subsp. *pseudocerris*
- *Quercus infectoria* subsp. *microphylla*
- *Ptosimopapus bracteatus*
- *Alyssum crenulatum*
- *Ptilostima diacantha*
- *Thymus cilicicum*
- *Salvia aramiensis*
- *Euphorbia cassia*
- *Genista cassia*

- *Colutea cilicica*

- *Centauria cassia*

Tools and Methods:

The following tools were utilized during the research:

- GPS device

- Probe for age estimation

- Soil samples and soil texture triangle for describing soil composition

- Munsell soil color chart for soil color determination

- Required analysis materials at the Agricultural Engineering College laboratory in Idlib

- Forestry measurement tools: 1) Height measurement device (Suunto) 2) Diameter measurement device 3) Caliper

- Statistical software: SPSS (26.0)

Forestry Sampling and Analysis:

After field surveying the Stone Pine Forest at the site, five circular samples, each covering an area of 400 m^2 with a radius of 11.3 m, were selected to represent homogeneous forest conditions with varying densities. The number of trees studied totaled 57. In each sample we measured: tree density (trees/ha), diameter at breast height (cm), tree height (m), form factor, basal area (m^2/ha), wood stock (m^3/ha), and annual growth (m^3/ha/year). These measurements were calculated using appropriate mathematical equations after determining the central tree in each sample and identifying its growth indicators.

- **Tree Density (N):** Calculated as the number of trees in the sample (n), then per hectare using the formula $N = \sum n / A$, where A is the sample area in hectares.

- **Diameter at Breast Height (dbh: 1.3m)**: The average diameter in the sample was calculated ((Parde´,1961, then averaged for the site and per hectare. Tree diameters were categorized into four classes with a range of 3 cm.

- **Tree Height (m):** Full tree height was measured in all samples, then averaged for each sample. Heights were distributed into classes differing by 2 m.

- **Basal Area:** The basal area (G) was calculated using the following equation: $G = \sum g$

Where:

- G: Basal area of the sample trees.

- g: Basal area of an individual tree.

Then, the average basal area per sample was calculated $G= \pi d^2/4$, followed by computing the final average basal area per hectare.

- **Middle Tree Identification and Study:** The central tree for each sample, representing the site, was determined as the tree with the median diameter, calculated as: $d' = \sum d(mean) / n'$, where

- d(mean) is the average diameter in each sample.

- n' is the number of samples at the site.

Subsequently, a series of measurements were conducted on the central tree for each sample.

Form Factor Calculation:

The form factor (f) represents the ratio between the volume of a stem and the volume of its equivalent cylinder, and its value is always less than one (Pretzsch, 2009). It was calculated according to Hüber (Sopp, 1974) in (Ibrahim, 2010) using the equation: $V = L \cdot Y$

Where:

- V: volume of the wooden piece (m^3)

- Y: cross-sectional area of the wooden piece at the midpoint (m^2)

- L: length of the wooden piece (m)

$f = \sum V / V'$

Where V is the volume of the equivalent cylinder.

Then, the average form factor for trees was calculated and used to compute the volumes of standing trees.

Wood Stock Calculation:

It was calculated according to the equation: $V = g \cdot h \cdot f$

Where:

- V: wood stock for each tree (m^3)

- g: basal area at breast height (m^2)

- h: tree height (m)

- f: average form factor

The wood stock was calculated in the sample and then per hectare: $V = \sum v \times 25$

Annual Average Growth Rate:

It is calculated according to the following equation: $AAG = V / t$

Where:

- AAG: annual average growth rate for the sample estimated in m^3/ha/year

- V: wood stock for the sample (m^3/ha)

- t: age of the forest stand (years)

Then, the average annual growth rate was calculated for each sample and per hectare.

Statistical analysis was conducted using Excel and SPSS by applying the Least Significant Difference (LSD) test at a significance level of 5% to study differences between samples means.

Results and Discussion

Analysis of the climatic data obtained from the nearest weather station, Baksariya, showed that the length of the dry period (Abbas, 1987) at the site reaches 187 days if $P \leq 4T$ is adopted. This value decreases to 135 days if $P \leq 2T$. Tables (1) and (2) present climatic data for the Baksariya station during the years 1985-2010 and the length of the dry period (ICARDA, 2010).

The area receives heavy rainfall with an annual average of 979.7 mm/year, most of which falls in the winter season with an average of 529 mm, followed by spring with an average rainfall of 248.2 mm. Autumn receives an average of 190.8 mm, while summer is the least rainy season with an average of 11.8 mm. The area follows a seasonal rainfall pattern (winter - spring - autumn - summer) and belongs to the humid bioclimate zone with a moderate variable, as depicted by plotting climatic data on a Emberger diagram (Figure 2).

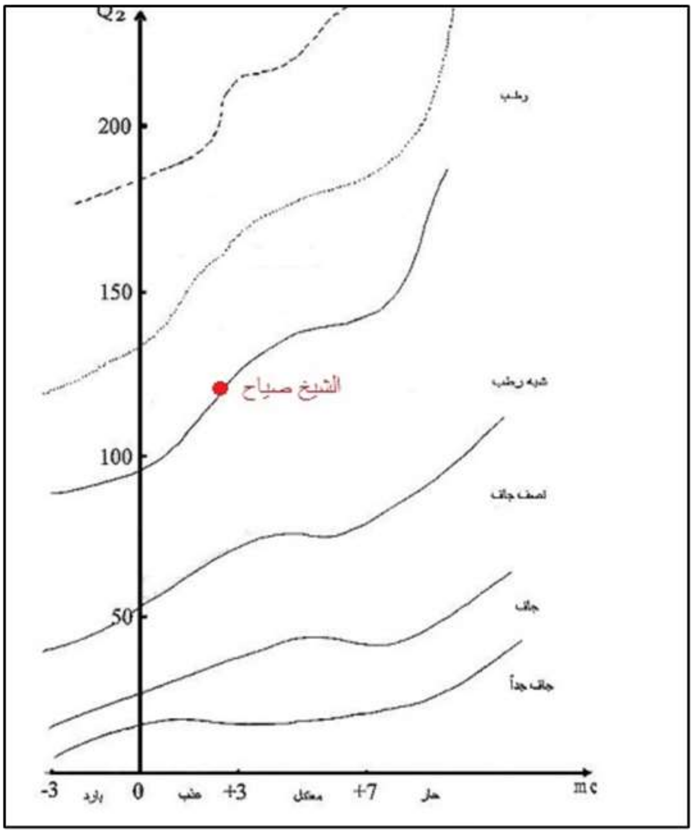


Figure 2: Bioclimatic Zone of the Studied Site on Emberger Diagram

Table 2: Climatic Data for Baksariya Station for the Years 1985-2010

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
P	214.9	153.1	129.7	66.7	51.8	9.7	0.6	1.5	3.7	76.1	111.0	161.0	**979.7**
M	10.3	12.3	16.2	22	26.9	30.6	33	33.2	31.7	26.2	17.6	11.6	**33.2**
m	4	4.2	6.9	10.9	14.8	18.8	21.4	21.6	19.1	14.7	8.6	4.9	**4**

Table 3: Length of the Dry Period at the Studied Site

Station	**M**	**m**	***Bioclimatic Zone***	**P(mm)**	**Length of Dry Period P≤ 4T**	**Length of Dry Period P≤2T**
Baksariya	33.2	4.0	Moderate humid	979.7	187 days	135 days

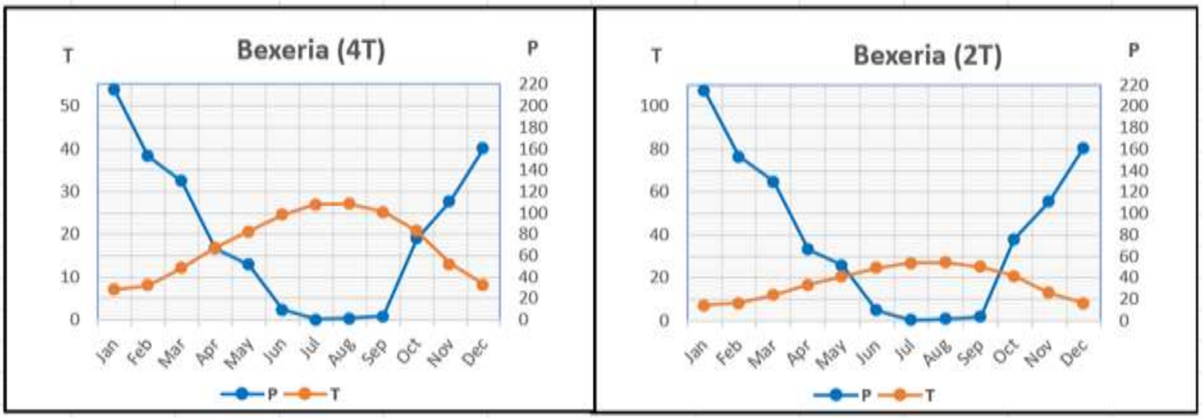


Figure 3: Length of the Dry Period at Sheikh Sayah Site

Regarding soil composition and texture:

The soil is loamy according to the soil texture triangle (Figure 4), and it contains a very small amount of calcium (3). It is slightly alkaline with a pH of 7.9 and rich in organic material (4.83%). It is non-saline (134 µS/cm) and poor in phosphorus (5 ppm) and has a low exchangeable potassium content (140 ppm). The soil composition consists of 19.7% clay, 51.2% sand, and 29.1% silt (Table 4).

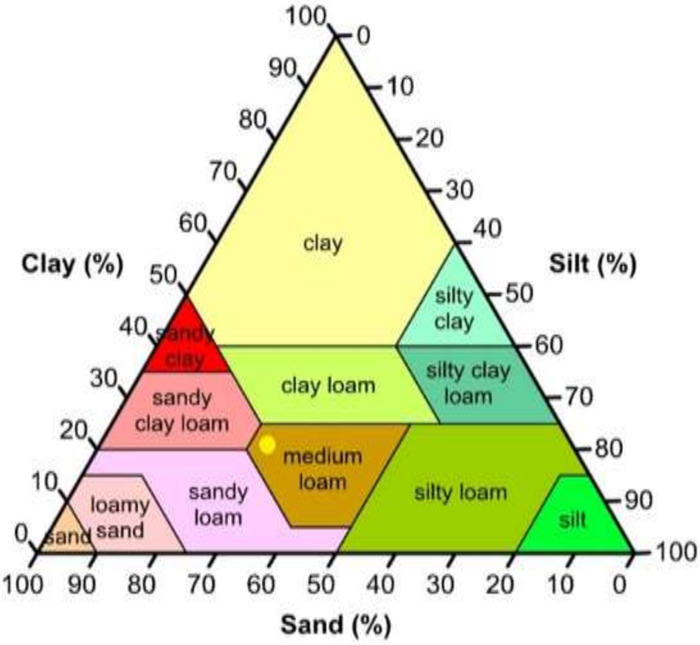


Figure 4: Mechanical Analysis and Soil Texture of the Site

Table 4: Chemical and Mechanical Composition of the Soil at the Site

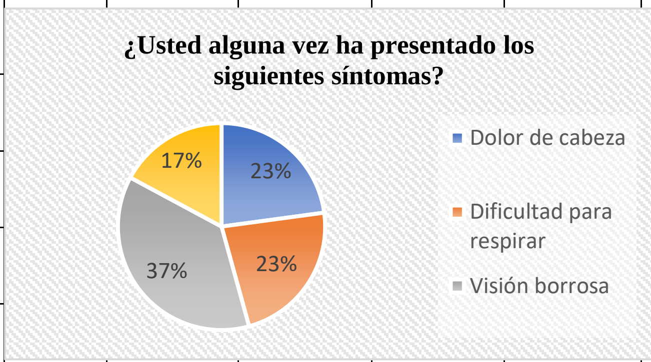
Sand (%)	Silt (%)	Clay (%)	Hydroscopic Moisture Content (%)	**P**	**K**	**Organic Material (%)**	**Na**	**Mg**	**Ca**	EC (µS/cm)	**PH**
				PPM			Quintessential/ 100 gr				
51.2	**29.1**	**19.7**	**3.8**	**5**	**140**	**4.83**	**1.2**	**3**	**3**	**134**	**7.9**

Middle Tree:

After the study, differences in the growth indicators of the middle trees of the studied samples were observed. It was found that wood production was low in some samples, such as in the second sample, with a rate of 11.3 m^3/h and an annual growth rate of only 0.45 m^3/h/year. In contrast, the highest wood production value (250 m^3/h) was observed in the first sample, with an annual growth rate of 2.01 m^3/h/year. This variation in growth rate within the same species can be attributed to differences in tree density (Table 5) and available growth conditions for the species in the studied samples. The density in the first sample was 375 trees/ha, while in the second sample, it was 200 trees/ha.

Table 5: Average Growth Indicators of Trees in Each Sample

	Number of trees	Dbh (m)	H (m)	G (m2/h)	V (m3/h)	AAG (m3/h/year)	N (tree/h)	*Form factor/ f*
***Average Sample*1**	15						375	0.84
Average Sample 2	8						200	0.89
Average Sample 3	11						275	0.86
Average Sample 4	13						325	0.88
Average Sample 5	10						250	0.84
Site Average	**11.4**	**0.165**	**6.17**	**6.38**	**34.6**	**1.38**	**285**	**0.86**



Density:

The average tree density for all samples at the site was 285 trees/ha. Sample 1 had the highest density at 375 trees/ha, followed by Sample 4 with 325 trees/ha, then Sample 3 with 275 trees/ha. Sample 5 had a density of 250 trees/ha, and finally Sample 2 had the lowest density at 200 trees/ha (Figure 3).

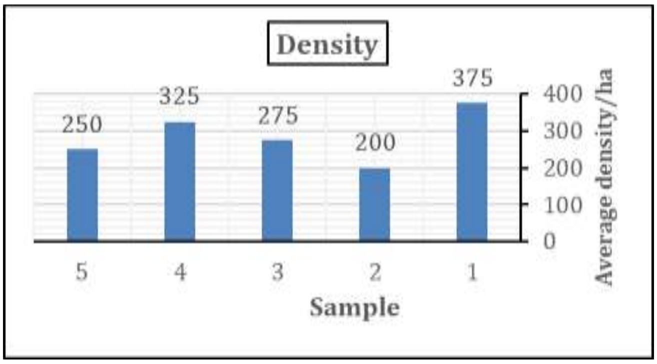


Figure 3: Density of Samples at the Site

Frequency Distribution of Diameters:

The diameters were distributed into four rows at the site. The dominance was for the row of 17 cm diameter with 27 trees, followed by the row of 20 cm diameter with 15 trees. Then, the row of 11 cm diameter had 14 trees, while the row of 20 cm represented the least number of trees, with only 4 trees (Figure 4).

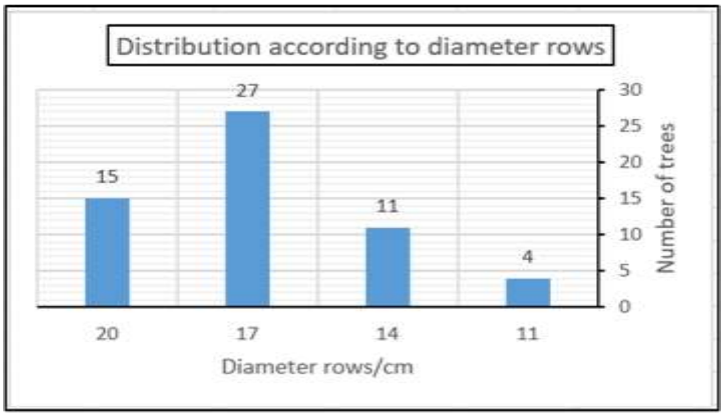


Figure 4: Distribution of Trees According to Diameter Rows

Average Diameter:

The average diameter for all site samples was 16.5 cm. Results of the LSD test indicated significant differences in diameter growth among the studied plots. Samples 1, 4, and 5 outperformed Sample 2 significantly at p-values of 0.002, 0.009, and 0.05, respectively. The highest average diameter value was observed in Sample 4 (18.01 ± 1.86 cm), followed by Sample 5 (17.7 ± 2.09 cm), then Sample 1 (16.8 ± 2.26 cm). Sample 3 had an average diameter of (16.2 ± 2.49 cm), and finally, Sample 2 had the lowest average diameter (13.9 ± 3.02 cm). The variation in soil physical properties and tree density may account for these differences (Figure 5).

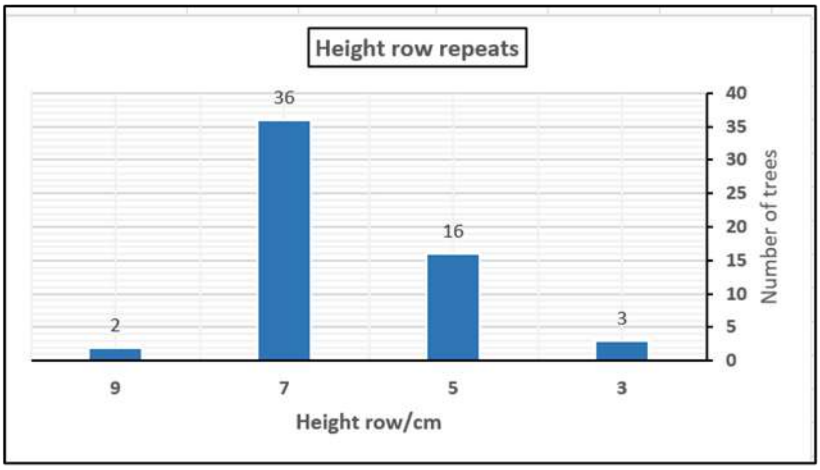


Figure 5: Distribution of Trees According to Diameter Averages

Frequency Distribution of Heights:

Heights were distributed into four rows at the site. The dominance was for the row of 7 m height with 36 trees, followed by the row of 5 m height with 16 trees. Small and large height rows had fewer trees, ranging from 2 trees for the 9 m row to 3 trees for the 3 m row (Figure 6).

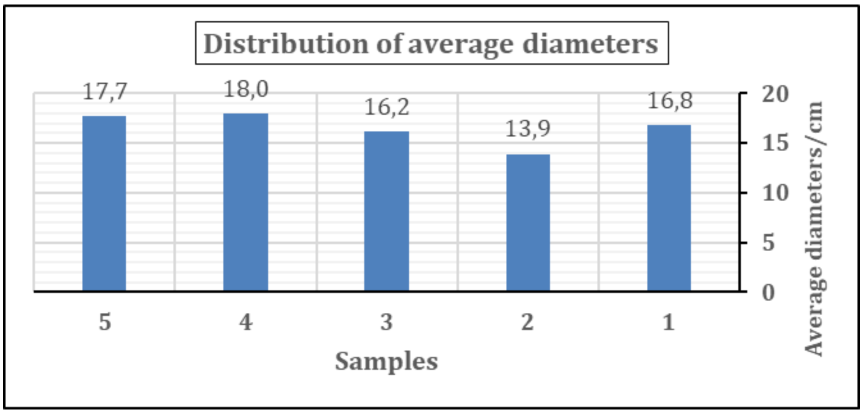


Figure 6: Distribution of Trees According to Height Rows

Average Height:

The average height for all site samples was 6.2 m. Results of the LSD test indicated significant differences in height growth among the studied samples. Sample 1 outperformed Samples 2 and 4 significantly at p-values of 0.000 and 0.005, respectively. The highest average height was observed in Sample 1 (7.2 ± 0.91 m), followed by Sample 5 (6.7 ± 0.53 m), then Sample 3 (6.5 ± 0.57 m). Sample 4 had an average height of 6.2 ± 0.66 m, and finally, Sample 2 had the lowest average height (4.2 ± 0.79 m) (Figure 7).

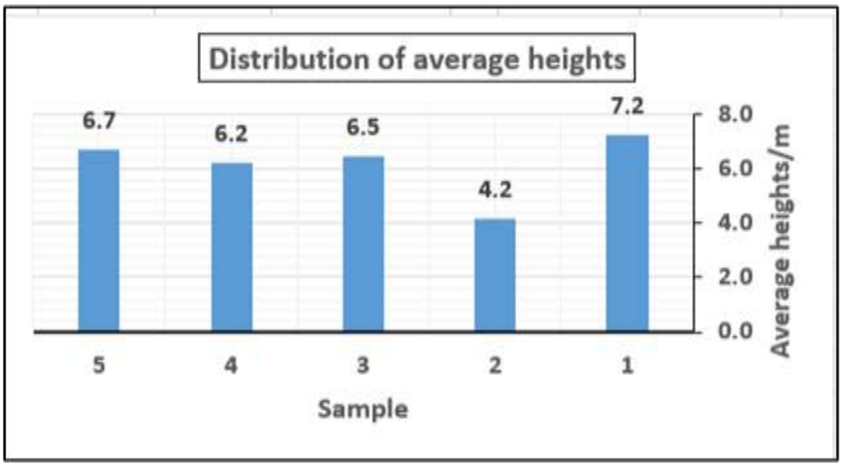


Figure 7: Distribution of Trees According to Height Averages

Basal Area:

The LSD test results revealed significant differences in basal area among the studied samples. The first and fourth samples outperformed the rest at a significance level of 0.05. The highest basal area value was recorded for trees in the first sample (8.27 ± 2.23 m^2), followed by the fourth sample (8.26 ± 1.71 m^2). The fifth sample exhibited an average basal area of (6.14 ± 1.52) m^2, while the third sample had an average basal area of (5.63 ± 1.73) m^2. Finally, the second sample had an average basal area of (3.03 ± 1.36) m^2. The average basal area for the site was 6.27 m^2/ha, which is notably lower compared to the findings of Farha (2014), where the average basal area was 21.32 m^2/ha. Additionally, it is lower than what was reported by Bravo *et al*. (2011) in southern Italy for a forest with a density of 612.7 trees/ha, where the basal area was 21.3 m^2/ha, and also lower than the average basal area in northwestern Tunisia, which was 23.27 m^2/ha (Sghaier *et al*., 2006). This disparity could be attributed to the lower tree density in the site and the nature of the underlying impermeable rock.

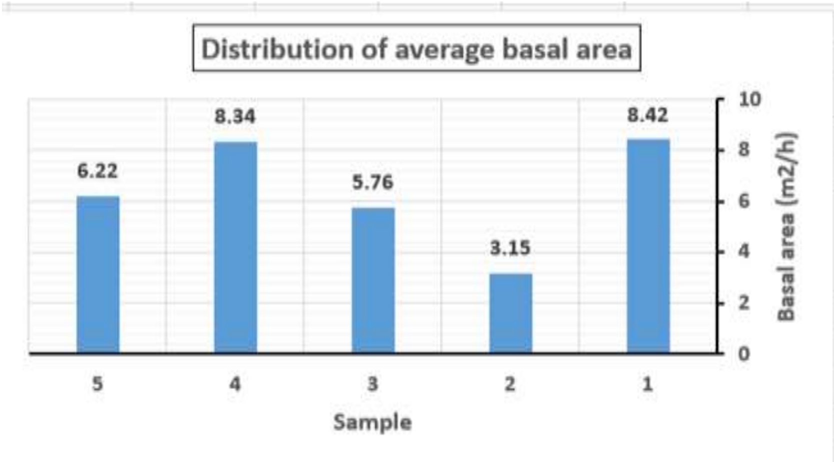


Figure 8: Distribution of Trees According to Basal Area Averages

Form Factor:

Partial volume determination was carried out for the selected tree from each compartment according to Huber's formula. For the selected tree in the first sample, the true volume was found to be 0.1378 m^3, and the equivalent cylinder volume was V̋= 0.164 m^3. Consequently, the form factor was calculated as follows: f =∑V / V̋= 0.84. The average form factor for the site was 0.86. In contrast, Ali (2004) reported a form factor value of 0.68 for Stone pine trees aged 43 years in the Dahr Al-Sawrani area in Tartous province. This supports Zoght's (1966) assertion that the form factor varies among trees and species, increasing with density and decreasing with age.

Wood Stock and Annual Growth Rate:

The study found that the average wood stock for all samples was 34.6 m^3/ha, which is relatively low compared to (Bravo et al. (2011)), who reported a wood stock of 116.3 m^3/ha and an average annual growth rate of 1.38 m^3/ha. The LSD test results indicated significant differences in wood stock and annual growth rate among the studied samples. The first sample outperformed the second, third, and fifth samples, while the third, fourth, and fifth samples outperformed the second sample at a significance level of 0.05. The highest wood stock value was recorded for the first sample (50.2 ± 15) m^3/ha, with an annual growth rate of (2.01 ± 0.6) m^3/ha/year. This could be attributed to the physical properties of the soil and the difference in tree density. Consequently, the longitudinal and diametric growth rates were better, affecting the wood stock and annual growth rate. The fourth sample followed with a wood stock of (38.5 ± 12.86) m^3/ha and an annual growth rate of (1.81 ± 0.51) m^3/ha/year. Next was the fifth sample with a wood stock of (34.7 ± 9.96) m^3/ha and an annual growth rate of (1.39 ± 0.39) m^3/ha/year. Then came the third sample with a wood stock of (31.4 ± 10.61) m^3/ha and an annual growth rate of (1.26 ± 0.42) m^3/ha/year, and finally, the second sample with a wood stock of (11.3 ± 6.47) m^3/ha and an annual growth rate of (0.45 ± 0.25) m^3/ha/year. The annual growth rate approached the limits reported by Nahal *et al*. (1996), where the average wood productivity was 2-0.5 m^3/ha/year for Stone pine in Syria, and in favorable conditions, the productivity could reach 10 m^3/ha/year. Ibrahim (2010) reported a wood stock of 268 m^3/ha and an annual growth rate of 10.71 m^3/ha/year for stone pine in the Jebel Al-Nabi Matta logging site in the upper-middle Mediterranean vegetation zone on soil of varying clay depth and clear forest floor thickness with an annual rainfall exceeding 1200 mm/year, The value of the wood stock reached 268 m/3h and the annual growth rate was 10.71 m/3h/year. While in a study by Farha (2014) at the Dahr Al-Sawrani logging site in Tartous province, the wood stock for Stone pine was 116 m^3/ha, with an annual growth rate of 4.45 m^3/ha/year at the age of 25-27.

Tukey HSD

(I) Samples	(J) Samples	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	39.2274*	5.2410	.000	24.418	54.037
	3	19.0441*	4.7521	.002	5.616	32.472
	4	4.6833	4.5363	.839	-8.135-	17.502
	5	15.9127*	4.8872	.016	2.102	29.723
2	1	-39.2274-*	5.2410	.000	-54.037-	-24.418-
	3	-20.1833-*	5.5625	.006	-35.902-	-4.465-
	4	-34.5441-*	5.3793	.000	-49.745-	-19.343-
	5	-23.3147-*	5.6784	.001	-39.361-	-7.269-
3	1	-19.0441-*	4.7521	.002	-32.472-	-5.616-
	2	20.1833*	5.5625	.006	4.465	35.902
	4	-14.3608-*	4.9043	.039	-28.219-	-.502-
	5	-3.1315-	5.2306	.975	-17.912-	11.649
4	1	-4.6833-	4.5363	.839	-17.502-	8.135
	2	34.5441*	5.3793	.000	19.343	49.745
	3	14.3608*	4.9043	.039	.502	28.219
	5	11.2294	5.0353	.185	-2.999-	25.458
5	1	-15.9127-*	4.8872	.016	-29.723-	-2.102-
	2	23.3147*	5.6784	.001	7.269	39.361
	3	3.1315	5.2306	.975	-11.649-	17.912
	4	-11.2294-	5.0353	.185	-25.458-	2.999

*. The mean difference is significant at the 0.05 level.

Figure 9: Statistical Analysis Results for Studied Samples Regarding Wood Stock and Annual Growth Rate

Conclusion

1. The feasibility of cultivating stone pine in sandy soil on green rocks is low, as the annual growth rate is only 1.38 m^3/ha compared to sites growing on limestone rocks where the growth rate reached 4.45 m^3/ha/year.

2. The study showed a decrease and variation in growth indicators in the studied samples, which may be attributed to variations in soil and parent rock properties, loss of cultivation and development practices, differences in tree spacing, and random encroachments on the site by local residents.

3. Species indicative of green rocks appeared, including *Ptosimopapus bracteatus*, *Quercus infectoria* subsp. *Microphylla*, and *Alyssum crenulatum*.

Recommendations:

1. Periodic implementation of appropriate cultivation and development operations to ensure that the trees receive the maximum amount of light without compromising the environmental protection role of the site.

2. Since stone pine is a multipurpose species, plans should be developed to determine the appropriate density to achieve good quantitative and qualitative specifications for timber and seed production, thus identifying the necessary cultivation methods to achieve this goal.

3. Continued study of this species in terms of timber and seed productivity and evaluation of its economic return.

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