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Assessing the evolution of the Aleppo Pine plantations by using field measurements and one-way Analysis of variance

Khaouani Boumediene[1], Hirche Azziz[2], Bouarfa Said[1], Berrabeh Djamaledine[1], Hadbaoui Ilyes[1], Youb Okkacha[1], Derdour Abdessamed[3].

[1]Scientific and Technical Research Center for Arid Regions (CRSTRA), Biskra, Algeria
[2]University of Sciences and Technologies Houari Boumediene, Faculty of Biological Sciences. Laboratory of Plant Ecology, Algeria
[3]Ctr Univ Naama, Department of Natural and Life Sciences; Laboratory for the Sustainable Management of Natural Resources in Arid and Semi-arid Zones. 45000. Algeria.

khaouani11@gmail.com

Abstract. Moudjbara area considered a gateway to Algeria's Great Sahara, was the first perimeter to be afforested with Aleppo pine in 1972 as part of a green dam initiative to combat desertification and preserve soil from wind erosion. This study examines the evolution of the species *Pinus Halepensis* Mill commonly known as the Aleppo pine in the Moudjbara plantations by comparing it to that of the natural forest of the Djellal Mountains in the Chergui region. Several field surveys were conducted, and four sites were selected in the natural forest and four sites in the Moudjbara afforestation. In each site, we performed 50 dendrometric measurements with 200 tree stakes. The selection is based on information on regeneration and plant quality. Stations are classified into four categories namely station of good regeneration, station slightly well regenerated, station moderately regenerated, and station of weak regeneration, which allow us to have primary reference data and to make a reliable assessment of the behavior of Aleppo pine in the Green Dam. The attribute ranking obtained from the ANOVA approximation provides us with crucial information of comparison between the natural forest and the reforestation zone. The results obtained can be used to adjust the planting density, rigorously choose the species, and adapt the soil preparation and planting techniques.

Keywords. Aleppo pine; forest; green dam; reforestation; dendrometric; environment and development.

1. Introduction

Desertification has had many definitions that have been the subject of intellectual controversy. Desertification is a myth that does not exist, according to opponents, whereas pro-desertification viewpoints defend its presence [1]. Despite an internationally negotiated and approved definition adopted at the United Nations (UN) Conference on Environment and Development (UNCED) in 1992, there is no clarity on what desertification is [2]. In addition to the political compromise, the Convention to Combat Desertification 'UNCCD' of 1994 proposed a consensus on this process: 'the degradation of land in arid, semi-arid and dry sub-humid areas as a result of various factors, including climatic variations and human activities, in particular, those resulting from overexploitation of the soil resulting from poverty' [3-7].

Algeria is the first largest African country, with two million km^2 of desert and 382,000 km^2 of semi-arid to sub-humid climate [8]. In Algeria, desertification mainly concerns the steppes of arid and semi-arid regions, which have always been the privileged space of extensive sheep breeding [9, 10]. Land degradation and desertification are the most advanced stages, reducing the biological potential and destroying the ecological and socio-economic balance [11-13]. They are subject to centuries of human exploitation in various practices varying in intensity according to the level of climatic aridity, population density, and local history of uses (Aidoud & Touffet, 1996).

Policies to combat desertification have been numerous and diversified (DGF, 2004). However, due to the lack of a unified global vision and the courageous choices of various governments, these policies have almost no convincing results, which makes the government unable to find coordinated preservation of the routes and an unlimited development plan. As part of protecting this vast territory from the threat of desertification, Algeria undertook a large-scale reforestation project just after independence. The project has a kind of vegetal wall called 'green dam', its first edition including the frustration of the advancing desert [14]. The field of intervention of the green dam is constituted by the pre-Saharan zone included between the isohyets 300 millimeters in the North and 200 millimeters in the south. The first reforested perimeter of Moudjbara in 1972 gave encouraging results [15, 16]. Plantations in the Moudjbara region remain a minority but have experienced a remarkable progression between 1972 and 1987 in the reforested area (Khaouani et al., 2019). The predicted increase in aridity in Algeria due to global climate change in the next decades has been widely accepted. It is projected to result in reduced rainfall and drought winters [17]. As a result, any knowledge on drought-tolerant plants that are planned to be planted in semi-arid environments is essential for planning afforestation or reforestation in these locations.

Initially, the green dam was meant to halt the desert's expansion into the country's north, with the goal of protecting natural resources, improving populations' living conditions, and preventing their exodus to metropolitan regions [14, 18-20]. Many authors have researched the evolution and current state of the Algerian green dam, and they have all stressed the green dam's inability to meet its intended goals, owing to a lack of planning, livestock overgrazing, and the project's lack of involvement of the local population [14, 18-20].

This study focuses on the region of Moudjbara, which is the first reforested limit in the framework of the Green Dam in Algeria. The lessons learned from the evolution of reforestation will be more accurate and precise; they will also allow us to obtain reliable information on the behavior of Aleppo pine in the reforestation of Moudjbara and anticipate problems through continuous analysis of this evolution. Therefore, it appears necessary to deepen the knowledge related to this reforestation through a synergy of different disciplines and to answer the question: What is its current state in relation to the problem of its regeneration?

2. Materials and methods

2.1. Administrative and Geographical Location

The study conducted on the reforestation of the forest Moudjbara in Ouled Djellal feet located in the region of Djelfa is part of the Algerian highlands, which is located in the Saharan Atlas, almost 300 kilometers south of Algiers (Figure 1). It’s located between 34°30'North and 3°28'East, and it covers a total area of 23,930.60 ha. This region is limited to the North by Djelfa and Dar Echioukh, to the South by Messaâd and Selmana, and to the East by Fidh Elbotma and

M'liliha the West by Ain Elbel and Deldoul. Its geographical location gives it a privileged place in the North-South relations of Algeria. It has an association of forest massifs distributed over much of its regional territory. The altitudes ranging between 1200 and 1400 meters, with an average altitude of 1049 m. It is characterized by a slightly rocky flat terrain with rather homogenous relief. The area's soils are dominated by low-evolved, shallow rendzine.

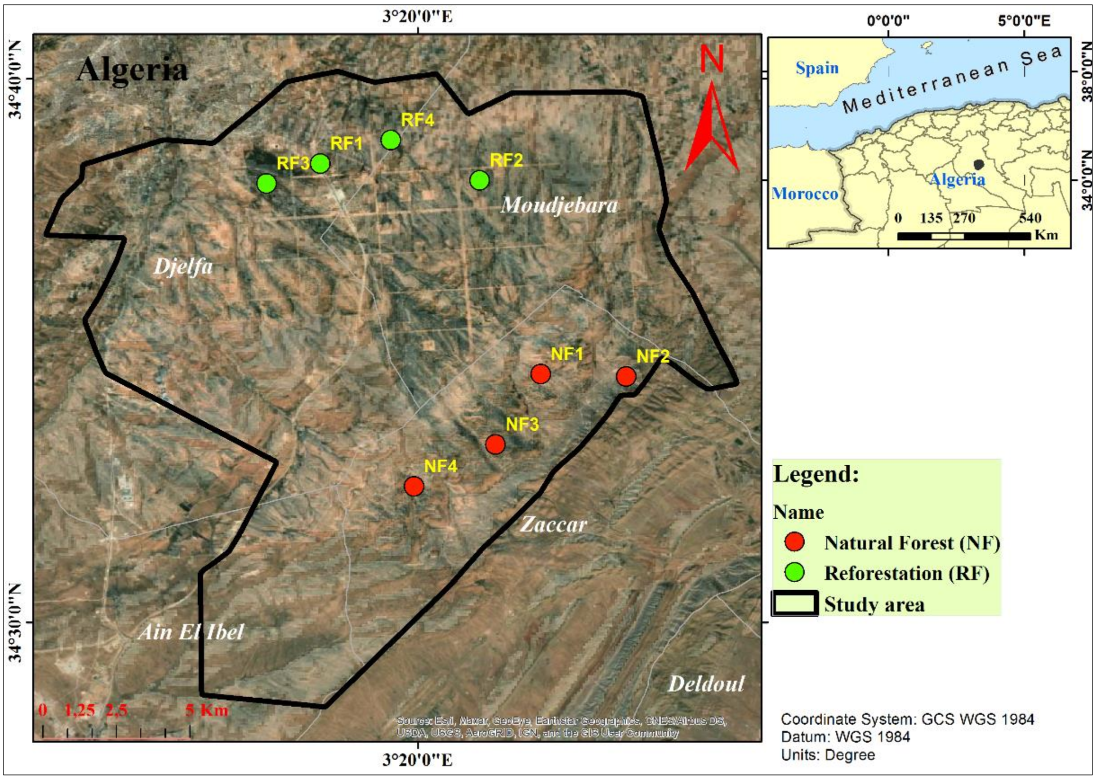

Figure 1. Study area.

The climatic data of 27 years (1988-2015) provided from the National Meteorological Office station, located at an altitude of 1150 meters and at coordinates 34'41 North latitude and 03'15 East longitude, revealed that the average precipitation is about 318 mm, the average of the of the maximum temperatures of the hottest month is 33.8 °C, and average of the minimum temperatures of the coldest month is 0.1 °C. The Emberger's pluviothermic quotient (Q2) for the study area is 33.57, which places the study area in the cool lower semi-arid stage [15].

2.2. Ground Data Collection

The field data used in this study were acquired during the field sampling period between 2019 and 2021 and consist primarily of dendrometric parameters. All the dendrometric data obtained underwent analysis and statistical treatment. We calculated the values of the dendrometric parameters (height, diameter at 1.30m, circumference, and estimated biovolume) of the average tree for each station. We performed a one-factor analysis of variance (ANOVA) and correlations between the different dendrometric parameters for the statistical analyses.

The dendrometric parameters were measured on 200 trees divided into four stations for the reforestation of Moudjbara and 200 other trees for the natural forest of Djebel Djellal. For the reforestation, we considered it preferable to divide the stations into two plots to obtain more information on the individuals and prove the observed homogeneity of the distribution of the individuals by the station. The choice is based on the feet' regeneration and quality (station with

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a good regeneration, station slightly good regenerated, station averagely regenerated, and station with weak regeneration). Regarding the natural forest, after several field surveys, we observed the opposite of what we saw in the planted area, namely that the individuals are distributed heterogeneously along the Ouled Djellal mountains. Therefore, the stations were chosen randomly, and data were taken without dividing the stations into two plots. This was considered unnecessary, especially since the purpose of this study is only to compare the situation of individuals in the Mujbara plantations with those in the natural forest.

2.2.1. Density

After several field surveys, we divided our study area into three forms: Good recovery; Medium recovery and Low overlay. In this study, we quantified the number of trees or stems on a hectare for each station. Density per hectare is based on the number of trees per unit area. This was calculated as described in Equation 1.

$$D = \frac{NP}{SP}, \quad (1)$$

Where:
D: Density per hectare,
SP: plot area in ha, and
NP: number of trees/plot.

2.2.2. Tree Height

The heights of tree were measured in the field by using a TruPulse laser rangefinder, an instrument designed for height measurements, as well as for distance measurements (Fig. 2). After several field surveys, we selected four sites for the natural forest (Table 1) and four for the reforestation of Moudjbara (Table 2). At each station, we made 50 dendrometric measurements from a total of 200 tree stakes. For reforestation, we divided each station into two plots in the same geomorphological conditions to have a maximum of information. The choice of stations is based on the regeneration and quality of feet (station with good regeneration, station slightly good regenerated, station moderately regenerated, and station with poor regeneration).

Figure 2. Measuring the height of a Tree with a TruPulse laser rangefinder.

Table 1. GPS locations of the natural forest stations.

Natural forest	GPS coordinates	Altitudes
Station 1	34°34.832' N/3°24. 131' E	1351m
Station 2	34°34. 409' N/3°23. 514' E	1362m
Station 3	34°34.224' N/3°2E3.692	1376m
Station 4	34°3304.4' N/ 3°23. 471' E	1347 m

Table 2. GPS locations of reforestation stations

Reforestation Moudjbara	GPS coordinates	Altitudes
Station 1	34°38.443' N/3°18.206' E	1165 m
Station 2	34°39.573' N/3°17.454' E	1170 m
Station 3	34°36.379' N/3°22.658'E	1293 m
Station 4	34°38.453' N/3°19.012' E	1192 m

2.2.3. Diameter Measurement

We used the forestry compass method (Fig. 4). Diameter and circumference are generally measured at 'person-height', i.e., at 1.3 m. The basal area corresponds to the surface of the tree section located at 1.3 m.

Figure 3.Diameter measurement with the forestry compass.

2.2.4. Counting the number of nests of the Aleppo pine

We counted the number of nests of the processionary caterpillar (Fig. 4) (the number one problem of Aleppo pine). After prospecting in the study area, two sites were selected; the first is located in the Moudjbara Green Dam plantation, and the second is in the Djellal Forest. We quantified the number of nests per tree on 200 subjects for each site. The pine processionary moth Thaumetopoea pityocampa is a key pine defoliator. Therefore, an inventory to count the number of nests in the Aleppo pine in the study area was carried out.

Figure 4.Winter nest of processionary caterpillar.

3. Results and Discussions

3.1. Density per Hectare

The notion of stand density is dynamic. It is modified over the years by the natural death of some trees or artificially by human action [21]. Tree density and site fertility can promote growth and influence cone production and the number of seeds stored in the canopy[22]. The values of average densities are 845; 1462; and 550 feet/ha, respectively, with a success rate of 42%, 73%, and 27% if we take into account the reference of Bensaïd [16] who mentioned that the plantations were made by 2000 feet per hectare while according to the technicians of the general direction of the forests of Djelfa the plantations were made for 1800 feet per hectare of which we obtained the following rates: 30%,81% and 46% by the altitudinal brackets of 1185, 1297, and 1165m.

Figure 5. Case of anarchic exploitation of the natural forest by a citizen.

The average density is higher in the reforestation Moudjbara with 1215, 66 stems per hectare against 410.83 at an average altitude of 1359m for the natural forest. This can be justified by the presence of dwellings where many residents carry out intensive wood exploitation in winter, often destructive in the natural forest (Fig. 5). At the same time, the high density of reforestation is due to the decision to plant 2000 seedlings per hectare in the initial plans of the green dam [16]. Silvicultural treatments, including thinning, must be carried out in the Moudjbara reforestation to limit competition and increase the living space for trees. In response to thinning, there is an increase in light, water, and nutrient availability in the stands[23]. These treatments can improve growth and reproduction parameters[24].

3.2. Category of Diameters

The trees in a stand may be of different sizes. Silviculture must assess the proportions of small, medium, large, and very large trees (Table. 3). The diameter of trees is quite simple to measure. For this reason, it is used to differentiate trees; we have divided the diameters into several categories. We estimated the diameter classes according to the measured dendrometric data. The structure was represented according to the diameter classes.

Table3. Category of diameters.

Categories	Diameter class
Small wood	2.5 to 12.5 cm
Medium wood	12.5 to 22.5 cm
Big wood	22,5 32,5 cm
Very large wood	≥ 32.5 cm

3.2.1. Reforestation Diameter Category

After the classification of the diameters according to the category of wood, we obtained the following classes:

- Small wood: this is the most dominant class with 106 (53%) individuals with a diameter between 2.5 and 12.5 cm.
- Medium wood: this class represents 32.5% of the total with about 65 feet, whose diameter varies between 12.5 cm and 22.5 cm.
- Large wood: 17 feet represent this category with a proportion of 8.5%.
- Very large wood: out of 200 trees measured, only 12 individuals, i.e., 6%, have a diameter greater than 32.5 cm.
-

3.2.2. Natural Forest Diameter Category

The classification of the diameters according to the category of wood gave us the following classes:

- Small wood: this class is absent; no tree has a diameter between 2.5 and 12.5 cm
- Medium wood: all measurements except five plants have a diameter between 12.5 and 22.5 cm.
- Large wood: 26 feet represent this category, corresponding to 13%.
- Very large wood: out of 200 trees measured, 169 have a diameter greater than 32.5 cm, or 84%. This is by far the most dominant class.

3.3. Height Classes

Table 4 lists the dimensional classification of graded softwood logs.

Table4. Dimensional classification of round wood for softwoods.

Length class	Length	Name
L1	< 3 m	Short wood
L2	3 - 6 m	Mid-length wood
L3	6 to 13.5 m	Long wood
L4	13.5 m and more	Very long wood

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3.3.1. Reforestation Height Classes

The classification of measured heights gave us the following classes:

- Shortwood: we have 40 short wood trees with a height lower than three meters with a rate of 20% of the total number of individuals.
- Mid-long wood: it is the most dominant class represented by 73 individuals with a proportion of 36.5%.
- Longwood: represented with 67 feet measuring between 6 and 13.5 m in height.
- Very long wood: this is the lowest class with a threshold of 10% presented by 20 feet.

3.3.2. Height Classes of the Natural Forest

After classification, we obtained the following classes:

- Shortwood: No tree is less than 3 m tall.
- Mid-long wood: only 4 trees out of 200 represent the mid-long wood class (i.e. 2%).
- Longwood: This is the most dominant class. 81.5% of the trees are between 6 and 13.5 m tall.
- Very long timber: Finally, the very long timber class is represented by 33 trees that exceed 13.5 m (16.5%).

Depending on the circumstances, this distribution can become asymmetrical, and its shape is dependent mainly on the silviculture practiced, the 'intensity of thinning', and natural mortality. At the global scale of reforestation, all diameter and height classes are present in very different proportions. This is because the afforestation process was set up in several stages and was also affected by several natural and human factors on the growth of seedlings under good conditions. Regarding the diameters, we observe a clear dominance of the category of small wood represented by 106 individuals, that is to say, 53% of the total number. The category of medium wood also has a significant presence, with 65 feet for 200 trees with an estimated proportion of 33%. Contrary to that at the level of the natural forest, these two categories are absent, which can be explained by the novelty of the afforestation, as it can also indicate the absence of the naturally reconstituted seedlings at the level of the natural forest. As for the categories of large wood and very large wood, we note and according to the results obtained, that they are represented by a large proportion at the level of the natural forest where we find approximately 82 % of the category very large wood against only 6% at the level of reforestation. Regarding these differences, we note that this is due to the difference in age of the stands between the two sites (the natural forest and older than the reforestation) and ecological conditions (slope; exposure; anthropic pressures, etc.). As for the height classes, the medium-long wood class is the most representative in the reforestation with a rate of 37%, while this class hardly represents the 2% for the natural forest. On the other hand, the very long wood class dominates the natural forest with 81.5% against 33.5% for reforestation, which shows the great difference between the two on the regeneration plan.

3.4. Dendrometric Characteristics of the Study Area

3.4.1. Moudjbara Stations

- Station (1)

Fig. 6 shows the distribution of the mean height and mean diameter of the two plots at station one. This is an artificial stand (reforestation); these are almost identical.

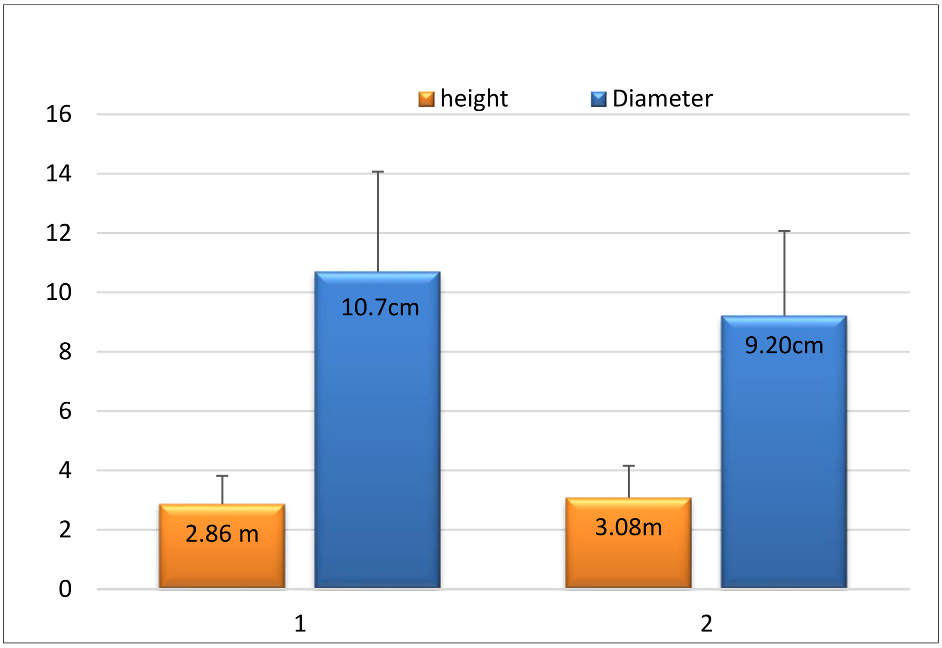

Fig. 6. Distribution of average height and average diameter of stems for Station 1.

They oscillate between 2.86 m and 3,08m in height on average successively with a maximum height of 6.88 m marked in the second plot by a single tree; as for the average diameter, it varies from 9.20 cm in the first plot to 10.7 cm for the second with a maximum of 19 cm. They were observed in both plots on three stems only, related to the 50 measured feet. It appears that the differences are not very noticeable. This is confirmed by calculating the standard deviation from comparing the two means. The ratio equals 0.6080, so since it is <1.96, there is no significant difference; H_o is accepted.

According to the results obtained, we note that the distributions of the two plots are quite similar, suggesting a certain homogeneity of the plots.

- Station (2)

Fig. 7 presents the distribution of the average height and average diameter of the two plots of the second station. This stand is reforested in more favorable conditions than the first station (on a wadi bed). The spacing between the plants curiously exceeds three meters, and they have a good regeneration compared to the previous station. They oscillate between 6,87m and 7,42m in height on average successively with a maximum height of 11.10 m observed in the second plot on a single tree; for the average diameter, it varies from 14.44 cm for the first plot to 18.64 cm for the second with a maximum of 32 cm observed in the second plot. We note that the two profiles are slightly different according to the results obtained, suggesting a low heterogeneity between the plots. The second plot even seems more homogeneous than the first one from the height point of view. The comparison of the two averages (reduced deviation) shows homogeneity between the two plots. Then the reduced deviation is lower than with1.96, a ratio estimated at 0.957, which the hypothesis H_0 for the equality of the averages is accepted.

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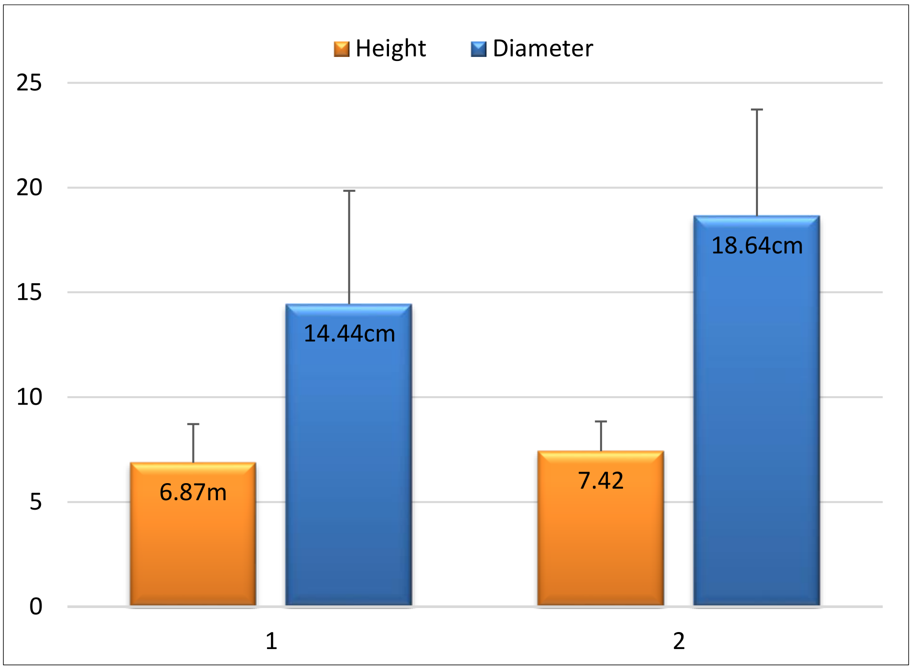

Fig. 7. Distribution of average height and average diameter of stems for Station 2.

- Station (3)

Fig. 8 shows the distribution of the average height and average diameter of the two plots chosen for this station. It is similar to the first station, and the average height varies between 3.66 m and 3.68 m successively with a maximum height of 6.10 m measured in the first plot on a single tree; as for the average diameter, it varies between 9.7 cm for the first plot and 10 cm for the second with a maximum of 18 cm observed in the first plot. According to the results obtained, the second plot seems more homogeneous. The established reduced difference shows a great similarity between the two plots, with a calculated p-value of 95.09%, which is higher than the significance threshold $\alpha = 0.05$. At the same time, the calculated ratio is also lower than 1.96 and equal to 0.0619 which means that there is no difference of means between the two plots.

- Station (4)

Fig. 9 shows the distribution of the average height and average diameter of the two plots of the fourth station. As this is a stand reforested under conditions similar to those of the second station (on a wadi bed), with a spacing between plants that generally exceed 3 m, the latter has been able to develop under more favorable conditions, which allows them a better regeneration rate relative to the other stations studied.

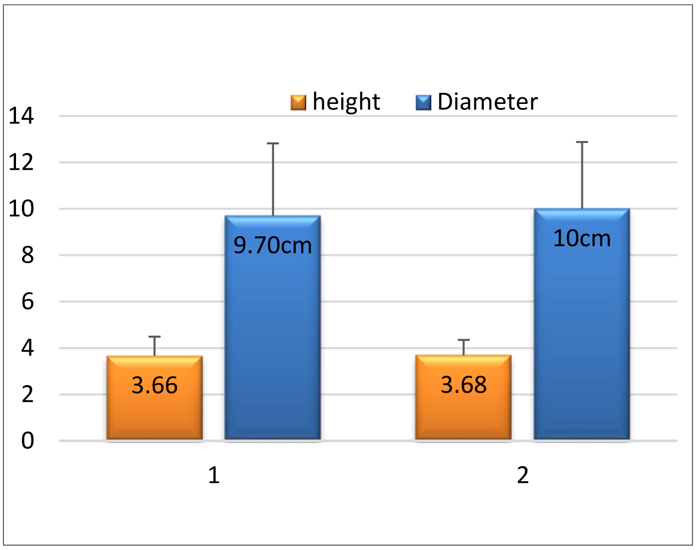

Fig. 8. Distribution of average height and average diameter of stems for Station 3.

The average height of the trees varies between 10.65 m and 14.55 m, with a maximum height of 16.40 m in the first plot. The average diameter varies from 24.6 cm in the first plot to 24.2 cm in the second plot, with a maximum of 54 cm in the first plot. According to the results obtained, the first plot is more homogeneous than the second. There is a difference in homogeneity between the two, the first showing values almost systematically higher than the second. The calculation of the reduced deviation determines that there is a difference in height means between the two plots ER and greater than 1.96 with a calculated ratio equal to 7.95.

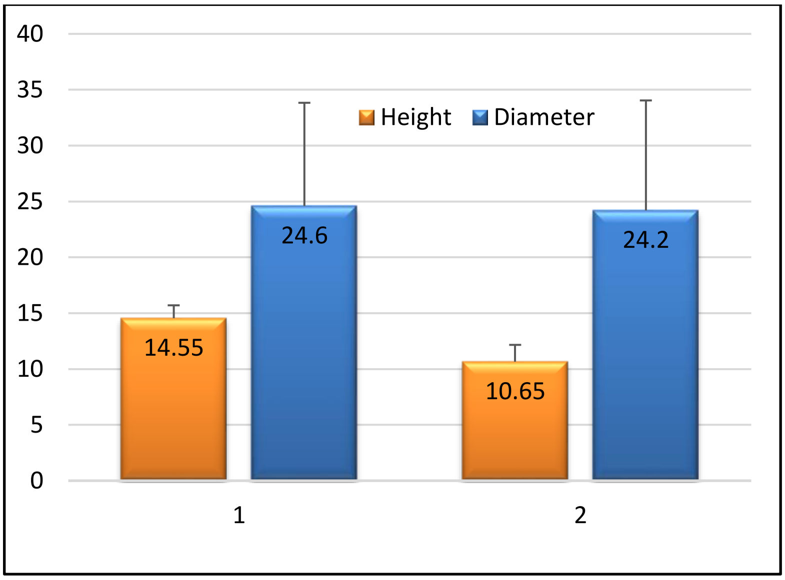

Fig. 9. Distribution of average height and average diameter of stems for Station 4.

As it is a stand reforested in similar conditions and the same period, we notice that the Aleppo Pine stands are quite homogeneous since their distributions through the statistical parameters are also homogeneous when there are differences. They are due to several parameters that intervene in the regeneration of the plants, such as the hydric network, anthropic pressure, the density that plays a significant role in the humidity of the soil, etc., and the anthropozoic pressure. One of the recommendations1 is the need to practice a wide spacing of the plantations in the arid zones to avoid competition in soil moisture.

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3.5. One-Way Analysis of Variance (ANOVA)

The comparison of the means of each parameter (height, diameter at 1.30 m, circumference, and volume of wood and number of nests per tree), for 200 measurements in the natural forest and similarly in the reforestation of Moudjbara, was done using XLSTAT 2009 software by applying the one-factor ANOVA test supplemented by a posthoc test of Newman and Keuls to highlight the homogeneous groups for each parameter. The results of ANOVA of different dendrometric parameters (Height, Circumference, and number of nests are given in Table 5, even for natural forest and reforestation project. Table 6 summarizes the results of the Newman and Keuls tests for each parameter of the study area.

Table 5. ANOVA of dendrometric parameters by the station.

Parameters	Site	Source	DDL	Sum of squares	Average of squares	F	Pr> F (p-value)
Height	Reforestation	Model	3	29011985,85	9670661.95	289.82	>0.0001***
		Error	196	6539876.5	33366.71		
		Corrected total	199	35551862.35			
	Natural Forest	Model	3	622079.840	207359.947	3.682	0.013
		Error	196	11038489.680	56318.825		
		Corrected total	199	11660569.520			
Circumference	Reforestation	Model	3	74311.707	24770.569	45.675	< 0.0001***
		Error	196	106296.280	542.328		
		Corrected total	199	180607.987			
	Natural Forest	Model	3	8398.802	2799.601	3.047	0.030
		Error	196	180078.101	918.766		
		Corrected total	199	188476.902			
Number of nests	Reforestation	Model	3	119.695	39.898	5.826	0.001***
		Error	196	1342.260	6.848		
		Corrected total	199	1461.955			
	Natural Forest	Model	3	129.615	43.205	2.951	0.034
		Error	196	2869.260	14.639		
		Corrected total	199	2998.875			

*** Very highly significant.

3.5.1. Comparison of height variations in reforestation

Examination of the results in Table 5 shows significant differences between the four stations very highly. Indeed, the p-value, being less than 0.05% (<0.0001), the difference is significant, and the null hypothesis must be rejected. In other words, the average height of the trees is unevenly distributed among the reforestation stations. The Newman and Keuls tests (Table 6) reveal the existence of three groups. The first (A) corresponds to Station 4, with an average height of 12.6m. The second group (B) includes Station 2 with an average height of 7.08 m. The heights are between 3.67 and 2.97m concern the last group (C), which includes stations 3 and 1 with the lowest averages.

3.5.2. Comparison of height variations in the Natural Forest

Table 5 shows no differences between the 4 stations at the 1% threshold, but on the other hand, the difference exists at the 5% threshold. Indeed, the p-value (Pr>F) shows that the value obtained is less than 0.5. In other words, the total height of the trees is more or less equally distributed among the different stations of the natural forest. The Newman and Keuls tests (Table 6) reveal the existence of three groups. The first (A) corresponds to station 3, with an average height of 11.67m. The second group (AB) includes stations 2 and 4 with average heights varying between 10.54m and 11.36m. Group B contains station 1 with an average height of 10.32m. This slight difference between the three groups can be considered insignificant. Still, we can explain the distribution to the presence of individuals at a high level of the mountain, which makes them less vulnerable to logging by human beings and the availability of better natural conditions than others. This can also positively affect the regeneration of trees, which leads to these differences.

3.5.3. Heigh:

Comparison of the height of natural forest vs. reforestation

The null hypothesis (Table 7) states that the average heights between natural forest and reforestation are equal. The p-value (0.0001%) is well below the significance level (p-value; $p < 0.05$) and is therefore highly significant, and we can confidently reject the null hypothesis and conclude that there is a significant difference between the average heights of the different plots of natural forest and reforestation. The Newman and Keuls tests (Table 8) show that group A represents natural forest and group B corresponds to reforestation. The forest and reforestation do not share a letter, indicating that the average height of the natural forest is much higher than that of the reforestation.

3.5.4. Circumference at 1.30 m of the Moudjbara reforestation

Examination of the results in Table 5 shows significant differences between the four stations very highly. In other words, the average tree circumference is unevenly distributed among the reforestation sites. The Newman and Keuls tests (Table 6) reveal the existence of three groups. The first (A) corresponds to station 4, with an average circumference of 76.65 cm. The second group (B) includes station 2 with an average circumference of 43.16 cm, and finally, group (C) contains stations 1 and 3 with the lowest average circumference varying between 28.67 and 30.34 cm.

3.5.5. Circumference at 1.30 m of natural forest

Examination of the results in Table 5 shows no differences between the four stations, i.e., tree circumference is on average similarly distributed between the stations and the forest. The Newman and Keuls tests (Table 6) reveal a single group (A) with a mean that varies between 124.9 cm and 139.22 cm. In other words, there does not seem to be any discrimination between these different groups.

3.5.6. Circumference at 1.30 (DBH): comparison of forest/reforestation

The p-value obtained (0.0001) is below the significance level of $p < 0.05$ (Table 9). It is very highly significant. We can reject the hypothesis and conclude that there is a large difference between the means of the circumference of the natural forest and those of the reforestation. The Newman and Keuls tests (Table 10) show two well-discriminated groups. The first group (A) corresponds to the natural forest with an average of 131.40 cm, and the group (B) with 44.71 corresponds to the reforestation. The natural forest has, on average, much higher circumferences than reforestation.

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Table 6. Newman and Keuls tests for each parameter.

Parameters	Site	Modality	Estimated average	Groups		
High	Reforestation	4	1260.640	A		
		2	708.100		B	
		3	367.520			C
		1	297.200			C
	Natural Forest	4	1167.600	A		
		2	1136.000	A	B	
		3	1054.200		B	
		1	1032.920		B	
Circumference	Reforestation	4	76.655	A		
		2	43.166		B	
		3	30.348			C
		1	28.676			C
	Natural Forest	4	139.228	A		
		3	136.464	A		
		1	125.160	A		
		2	124.909	A		
Number of nests	Reforestation	2	3.560	A		
		3	2.880	A		
		4	1.780		B	
		1	1.720		B	
	Natural Forest	1	4.820	A		
		2	4.300	A	B	
		3	4.300	A	B	
		4	2.680		B	

Table 7. ANOVA of the average height of forest/ reforestation.

Source	DDL	Sum of squares	Average of squares	F	Pr> F
Model	1	19299766.923	19299766.923	162.697	< 0.0001***
Error	398	47212431.875	118624.201		
Corrected total	399	66512198.798			

*** Very highly significant.

Table 8. Newman and Keuls tests of average forest/reforestation height.

Modality	Estimated average	Groups	
Forest	1097.680	**A**	
Reforestation	658.365		**B**

Table 9. ANOVA of natural forest/reforestation circumference.

Source	DDL	Sum of squares	Average of squares	F	Pr> F
Model	1	752194.401	752194.401	811.12	< 0.0001***
Error	398	369084.890	927.349		

Corrected total	399	1121279.290

*** Very highly significant.

Table 10. Newman and Keuls tests of natural forest/reforestation circumference.

Modality	Estimated average	Groups	
Forest	131.440	A	
Reforestation	44.711		B

3.5.7. Number of nests per tree for each reforestation station

The p-value obtained (0.001) is below the significance level $p < 0.05$ (Table 5). The null hypothesis is rejected. The number of nests is different between stations with respect to reforestation. The Newman and Keuls tests (Table 6) show that two groups stand out; group (A), which contains stations 2 and 3 with an average that varies between 2.88 and 3.56, and group (B) for the first and fourth station with an average that varies between 1.72 and 1.78 nests per tree. This difference can be explained after the field trips and surveys in the different stations. Stations3 and 4are located near the municipal road leading to the city of Moudjbara and, secondly, the presence of these stations near the observation house of the Directorate of Forestry proves that the individuals of the Aleppo pine have obtained a higher degree of protection and resistance, unlike the second and third stations, which are located well beyond what made them less vulnerable to surveillance.

3.5.8. Number of nests per tree for each station in the natural forest

Table 5 shows no major differences between the four stations at the 5% threshold, but differences exist if we use the 1% threshold. We can notice that the p-value (0.034) is not far from the limit value (0.05) at the 5% risk threshold. Thus, the number of nests per tree is quite homogeneous between the different stations, but this homogeneity is relative to the risk threshold retained. The Newman and Keuls tests (Table 6) reveal the existence of three groups, the first (A) corresponds to station 1 with an average of 4.8 nests per tree, the second group (B) includes station 4 with an average of 2.6 nests per tree and finally the group (AB) which contains stations 2 and 3 which share the same letters A and B which means that they have the same number of nests per tree. This corroborates our previous remark about the great similarity between the stations. Only Station 4 stands out clearly from the other three. Firstly, we can note that the distribution of the processionary caterpillars on the trees was not regular. We noticed that most of the attacked trees were those with branches close to the ground. At the same time, the nests were also located on only one side of the tree, the southern one. For Station 4, we considered it the best in terms of diameter and length because it was located between two slopes. We think that all these indicators made them more resistant than the individuals of the other stations.

3.5.9. Number of nests per tree for each natural forest/reforestation station

Examination of the results in Table 11 shows significant differences between natural forest and reforestation very highly. In other words, the number of nests per tree is unevenly distributed between natural forest and reforestation. The Newman and Keuls tests (Table 12) show that there are two groups; group (A), which represents the natural forest with an average of 4.02 nests per tree, and group (B), which corresponds to reforestation with an average of 2.48 nests per tree.

Table 11. ANOVA number of nests per tree natural forest/reforestation.

Source	DDL	Sum of squares	Average of squares	F	Pr> F
Model	1	237.160	237.160	21.160	< 0.0001***
Error	398	4460.830	11.208		

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Corrected total	399	4697.990

*** Very highly significant.

Table 12. Newman Keuls test - number of nests per tree; natural forest/reforestation.

Modality	Estimated average	Groups	
Forest	4.025	A	
Reforestation	2.485		B

3.6. Correlations

The dendrometric data were statistically processed, and we performed correlations of the different parameters measured and estimated their relationship between the reforestation and natural forest sites. One of the main questions is whether there is a relationship between infestation (number of nests) and tree vigor.

3.6.1. Correlation between different dendrometric parameters in natural forest

From the results (Table 13), the Pearson correlation coefficient data shows that there is no relationship between the number of nests and the different dendrometric parameters; while the p-values (Table 14) between the parameters height, diameter, circumference, and volume are below the significance level, which indicates that there is not a great relationship with the dendrometric parameters. In other hand, Pearson's r = 0.788 shows a largely positive relationship. Most points fall near the line (Fig. 10), indicating a strong linear relationship between tree height and diameter. The relationship is positive because as height increases, diameter also increases.

Table 13. Correlation between different dendrometric parameters (natural forest).

Variables	Nest	h/cm	Ø (cm)	Biov	Cir/cm
Nest	1	0.093	0.039	0.057	0.039
H (cm)	0.093	1	0.788	0.853	0.788
Ø/ cm	0.039	0.788	1	0.949	1.000
Biov	0.057	0.853	0.949	1	0.949
Cir/cm	0.039	0.788	1.000	0.949	1

Values in bold are different from 0 at significance level alpha=0.05

Table 14. p-value (natural forest).

Variables	Nest	h/cm	Ø/ cm	Biov	Cir/cm
Nest	0				
h/cm	0.189	0	< 0.0001	< 0.0001	< 0.0001
Ø/ cm	0.588	< 0.0001	0	< 0.0001	< 0.0001
Biov	0.424	< 0.0001	< 0.0001	0	< 0.0001
Cir/cm	0.588	< 0.0001	< 0.0001	< 0.0001	0

Values in bold are different from 0 at significance level alpha=0.05

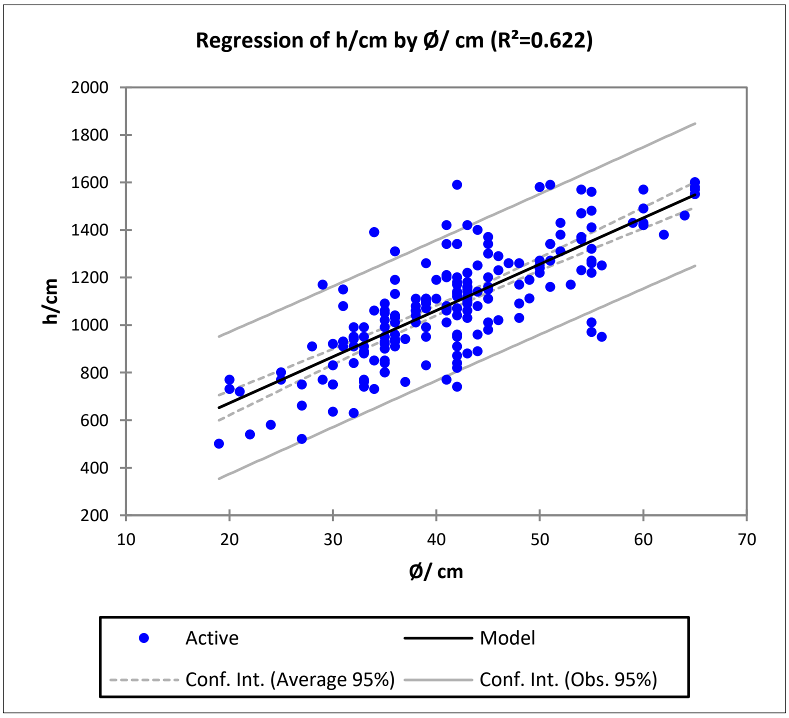

Figure 10. The regression line between height and circumference (natural forest).

3.6.2. Correlation between different dendrometric parameters of reforestation

From the results (Table 15), the Pearson correlation data shows a very weak relationship between the number of nests and the parameters of diameter and circumference. At the same time, there is a fairly good relationship between height and biovolume, which is logical. On the other hand, (Table 16) the parameters height, diameter, circumference, and volume have p-values below the significance level, indicating a very strong relationship with the dendrometric parameters. Pearson's r = 0.733 has a largely positive relationship. Most points fall near the line (Fig. 11), indicating a linear relationship between tree height and circumference. The relationship is positive because as height increases, so does circumference.

Table 15. Correlation between the different dendrometric parameters (Reforestation).

Variables	Nest	h/cm	Ø/ cm	Biov	Cir/cm
Nest	1	0.013	0.264	0.066	0.264
h/cm	0.013	1	0.733	0.671	0.733
Ø/ cm	0.264	0.733	1	0.895	1.000
Biov	0.066	0.671	0.895	1	0.895
Cir/cm	0.264	0.733	1.000	0.895	1

Values in bold are different from 0 at significance level alpha=0.05

Table 16. p-value (Reforestation).

Variables	Nest	h/cm	Ø/ cm	Biov	Cir/cm
Nest	0	0.858	0.000	0.354	0.000
h/cm	0.858	0	< 0.0001	< 0.0001	< 0.0001
Ø/ cm	0.000	< 0.0001	0	< 0.0001	< 0.0001

Biov	0.354	< 0.0001	< 0.0001	0	< 0.0001
Cir/cm	0.000	< 0.0001	< 0.0001	< 0.0001	0

Values in bold are different from 0 at significance level alpha=0.05

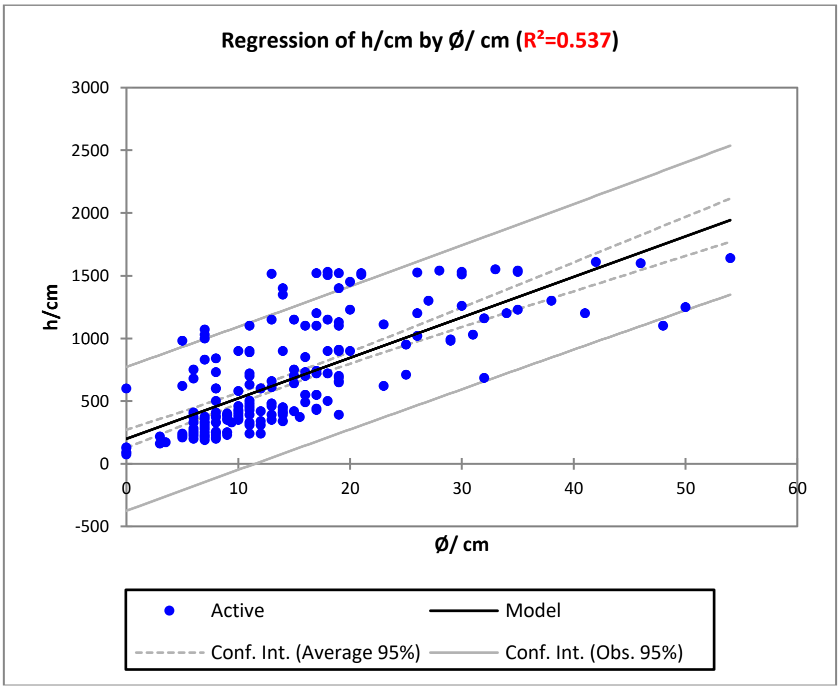

Fig. 11. The regression line between height and circumference.

4. Conclusion

This work focused on the Moudjbara region located in the Djelfa region. The lessons learned from the evolution of the Green Dam in this region, which is not necessarily representative of the entire Green Dam, could be more refined and more precise; they will also allow not only to obtain reliable information on the physiognomic evolution of the 'Green Dam' in the study area but also to anticipate possible problems thanks to the continuous analysis of this evolution. Climatological data, particularly the irregularity of rainfall with periods of drought, have probably contributed to the poor regeneration of the reforested stands. The dendrometric results show that the Aleppo pine of the reforestation of “Moudjbara” is not as pleasant as that of the natural forest. Indeed, the statistics of the different sampled plots show that the plantations, which simulate a young forest (even-aged), have an average height that does not exceed 6.5 m and 44 cm in circumference after 40 years of growth, while the natural forest reaches 11 m in height on average and 131cm in circumference, which represents rather a mature forest playing a role of seed. It must be said that this difference between the two stations (natural forest/reforestation) and due first to the age of the plantation, then to the variety of environments and their complexity. However, these dendrometric differences can also be attributed to the plantation density, causing severe competition between shrubs. Other factors may explain this contrast, such as the absence of silvicultural treatments during this stand’s different stages of evolution. During the different field trips, we noticed that the natural cutting was insufficient, thus favoring the growth of secondary branches to the detriment of the trunk. The natural regeneration of Aleppo pine at the level of Moudjbara also poses a major problem in the face of parasitic attacks (caterpillars) that feed on young plants, thus making any possibility of regeneration difficult. The phytosanitary aspect must be considered because, like all monospecific stands, they are vulnerable to pathologies. However, we found Aleppo pine stands in better condition in the natural forest than in the Moudjbara reforestation. Following these results, it is recommended that the managers opt for the diversification of plants and the Aleppo pine and the introduction of other useful plants such as rustic fruit species or fodder. It is also necessary to apply adequate forest management (silvicultural operations, realization of infrastructures of firebreak trench, tracks, etc.) based on the treatment in a regular forest to preserve the national forest heritage. These initial results can be used as a decision-making tool to implement reforestation projects using the most suitable species in the Green Dam area in the context of the fight against biodiversity loss.

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