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# Hydric behavior of four Atlas cedar (*Cedrus atlantica* M.) seedlings in the face of a water deficit on two types of substrate

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**Abstract**
The current state of the Moroccan cedars is worrying and it would be no less in the future years, especially in view of climate change which, most likely, would be manifested by an increase in temperatures and a reduction in precipitation. Decaying cedar trees, the scarcity of natural regeneration, the difficulty of artificial regeneration and the reduction of its range are all manifestations of the dysfunction of this ecosystem.

To better understand the ecophysiological mechanisms related to water stress in Atlas cedar (*Cedrus atlantica* M.), an experimental device was installed in nurseries on plants from four provenance regions: Tizi Ifri (Rif), Sidi M 'guild (Middle Western Atlas), Tamtroucht (Middle Eastern Atlas) and Bouadel (Eastern High Atlas). These plants, transplanted at 9 months on calcareous and basaltic substrates were subjected to water stress by watering shutdown at the age of 17 months. The parameters of plant water relationships that are significantly related to changes in soil conditions and water availability were estimated during this period.

The results show that at the end of the drying test, on basaltic substrate, the provenance of Sidi M'guild stood out significantly from the other sources by a pre-blooming water potential Ψb (-27.81 bars) and a potential water of midday Ψm (-29.75 bars) less negative, a daily amplitude of the water potential of the order (1,93 bars). On calcareous soil, the Bouadel and Tamtroucht provenances recorded close and less negative values for all the parameters measured. The provenance of Tizi Ifri is the least tolerant to water stress with the most negative values for Ψb and Ψm and a lower daily amplitude. These results show the highest performance of Sidi M'guild provenances on basaltic substrate and Bouadel and Tamtroucht on limestone substrate as regards their resistance to water stress. This work helps guide managers towards choosing the most suitable provenances for environmental conditions.

**Keywords:** *Cedrus atlantica* M., provenances, culture substrate, water stress, ecophysiology, Morocco

## 1. Introduction

In Morocco, cedar forests (*Cedrus atlantica* Manetti) cover an area of 133 000 hectares and the main massifs are found in the Rif, the central and eastern Middle Atlas and the Eastern High Atlas [1, 2]. Throughout their natural range, the cedar groves are found between 1500 and 2600 m altitude [3]. They settle on different types of substrates [4, 5, 6] and receive between 500 mm and 2000 mm of rain per year [6].

Cedar is considered a noble species, it has always been of great importance both ecologically and socio-economically, because it is a multifunctional species on the one hand by the production of wood, fodder and activities. Ecotourism, hunting and fishing and on the other hand a protective heritage of soils, waters and biological diversity [7].

But, in recent decades, Atlas cedar (*Cedrus atlantica* Manetti), a forest species that constitutes a natural heritage for Morocco and the humanity, is exposed to climatic, social and technical constraints. Decaying cedar trees, the absence or scarcity of natural regeneration, and the reduction of its range are all manifestations of ecosystem malfunction of cedar forest. Therfore, the search for phenomena directly related to cedar dieback is a major challenge that would reverse the situation and act properly by defining a better preservation strategy based on sustainable management [8]. The current state of Moroccan cedar forests is very worrying, and it would not be less so in the years to come, particularly in view of the global climate change that would be manifested by an increase in temperatures and a reduction in rainfall [9, 10, 11, 12].

In order to ensure the sustainability and normal functioning of the ecosystem of the Atlas cedar, the Office of the High Commissioner for Water and Forests, and the Combating Desertification (OHCWFHCD) has undertaken strategic measures for the reconstruction and regeneration of this essence and its adaptation to the various stressors, especially drought. The latter has become more and more recurrent in recent years and can act as a predisposing factor and / or trigger the process of withering, constitutes a major challenge that would reverse the situation and act appropriately in determining a better preservation behavior based on sustainable management.

Among the scientific approaches capable of providing valuable information on the behavior of Atlas cedar, ecophysiology is considered as a tool based, among other things, on the analysis of parameters of water relations, gas exchange and growth of the plant. It will guarantee the upstream understanding of the cedar dieback phenomenon and will make it possible to propose adequate solutions in the management of cedar forests, especially silvicultural treatments to achieve natural and artificial regeneration [13, 14]. Thus, in order to contribute to the production of cedar plants resistant to drought, it is proposed, in this study, to evaluate the ecophysiological behavior of four cedar provenances of the atlas: Tizi ifri (Rif), Sidi M'guild (Middle Atlas Central), Tamtroucht (Middle Eastern Atlas) and Bouadel (Eastern High Atlas) subjected to water stress caused on 17-month-old seedlings transplanted on limestone and basaltic substrate at the nursery to determine the or provenances resistant to drought.

## 2. Materials and Methods

This study evaluates the behavior due to water stress of four provenances of cedar plants from different seed stands: Tizifri of the Rif, Sidi M'guild of the central Middle Atlas, Bouadel of the Eastern High Atlas and Tamtroucht of the Middle Eastern Atlas. Pedoclimatic and ombrothermal characteristics are given in Table 1.

**Table 1:** Stand of cedar seed by region of provenance [15, 16, 17].

| Region of provenance | Stand Name | Area (ha) | Altitude (m) | Latitude N | Average annual rainfall (mm) | Mother stone | Soil texture | Bioclimatic floor | Extreme temperatures (°C) Max. Min. | |
|---|---|---|---|---|---|---|---|---|---|---|
| Middle Atlas Central | Sidi M'guild | 340 | 1880 | 33°12' | 884 | Dolomite + limestone | Silt Clay | Subhumid with cold winter | 30.9 to 27.6 °C | -4.7 to -0.5 °C |
| Middle Eastern Atlas | Tamtroucht | 25 | 1800 | 33°48' | 765 | Marno-Shale | Silt Clay Sand | Subhumid with cold winter | 28.7 to 26.5 °C | -6.4 to 3 °C |
| Haut Atlas oriental | Bouadel | 202 | 2090 | 32°27' | 415 | Limestone | Clayey | Subhumid withcold winter | 29.6 to 23.2 °C | -8.3 to -3.1 °C |
| Western Rif | Tizi ifri | 229 | 1820 | 34°51' | 1103 | Quartzite Schist and Sandstone, Limestone | Silt clay sand | Subhumid with cold winter | 28.8 to 23.7 °C | -5.6 to -0.4 °C |

- **Plant production**

The seeds used in this experiment were provided by the Regional Seed Centers of Chefchaouen (Rif) and Azrou (Middle Atlas) under the OHCWFHCD. After stratification of the seeds, the Azrou forest nursery, they were sown, in March 2010, in containers of 300 cc., 3 seeds per cell, filled with culture substrate usually used in the nursery. In order to ensure proper root autocerning, the racks were raised. After seed germination, the seedlings were individualized and transplanted to one another [18].

The experimental setup was conducted in random block, consisting of 216 plants per provenance. The plants were watered daily twice a day. In March 2011, half of these plants, or 108 plants per provenance, were transplanted into 20-liter polyethylene sachets filled with a calcareous substrate taken from the Boutrouba forest in Tizi Ntghten on the Michlifen road in the Aït Youssi Amklaet region and the other half by a basaltic substrate taken from Azrou Township Sheb forest [18] (Fig.1).

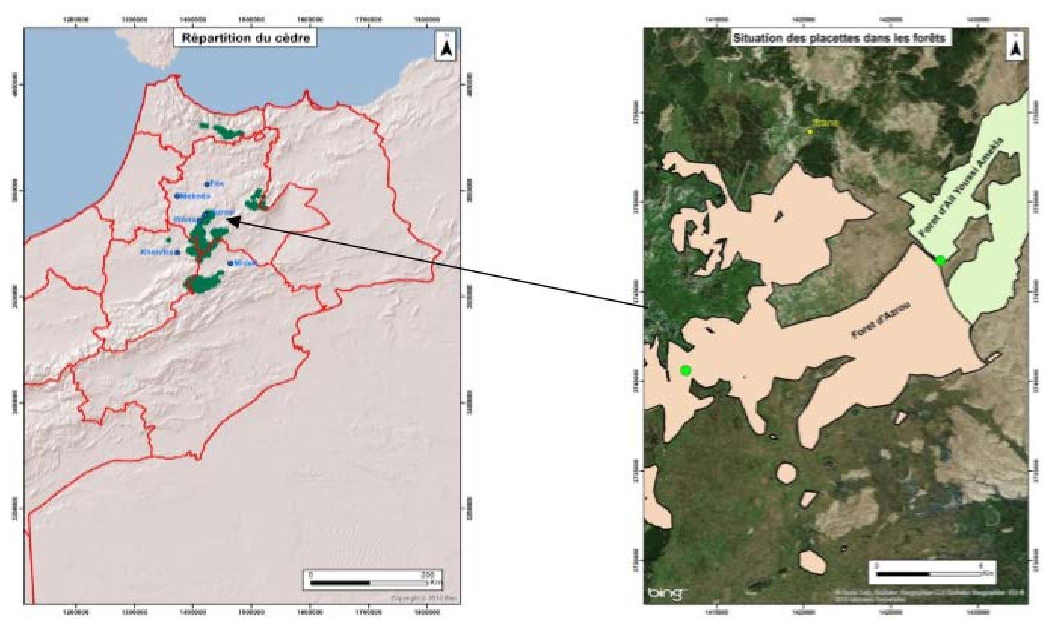

**Fig 1**: Distribution of cedar in the northern part of Morocco. And geographical location (●) of sampling locations of the two used substrate

At the age of 17 months these plants were subjected to water stress by watering stop. The application of water stress occurred from July 27, 2011 to September 06, 2011, the date corresponding to the appearance of the signs of drying and a yellowing of the needles of the plants almost generalized. The dewatering test lasted 42 days. Moreover, the experimental device is conducted in random block included the stressed plants and those controls daily watered at a rate of once a day. During the test, the plants were protected against humidification of the growing media during the night and rainy days.

Measurements of the relative water content of the substrate were made three times during the water drying test. After 14 days, 21 days and at the end (42 days), a sample of the substrate was taken to determine its relative water content at 3 replicates per substrate and per sample. The water content of the substrate (WCS) was estimated after steaming the samples for 48 hours at a temperature of 60 °C. It was calculated according to the following formula:

$$\textbf{RWCS (\%)} = \frac{\text{Wet weight - Dry weight}}{\text{Dry weight}} \times 100$$

Two weeks after the launch of the dewatering test, monitoring of the effect of water stress was assessed weekly by measuring basal leaf water potential (pre-dawn) (Ψb) at 4: 00 am and water potential from noon (Ψm) to 13 hours. The maximum daily amplitude (Δψ w) is the absolute value of the difference between the midday and baseline water potential. The critical water potential (ψc) corresponds to the most negative base potential when the daily amplitude of the water potential is very low or even zero [14]. Note that according to Aussenac and Granierv (1978) [19] we speak of ψc when Δψ w is less than 4 bars for a beautiful day.

Leaf water potential was measured using the Scholander pressure chamber (PMS, Corvallis, Oregon, USA), the basal end of a 12 cm to 15 cm long leafy shoot is introduced into the chamber, in steel, where the compressed nitrogen is sent until the pressure is sufficient for the sap to escape through the severed portion [20]. Each measurement was subjected to three (3) repetitions by source and by type of substrate.

By convention, the water potential is of negative sign but to facilitate the use of the obtained data, the graphs were constructed using the absolute values of the data.

- **Data statistical treatment**

In the static analysis of the data, the multiple comparison of the averages of the various factors and measured parameters of the four provenances is carried out by Statistical Analysis System (SAS) software version 9.4 with the Ducan test at "a = 0.05 ".

## Results

- **Relative water content of the substrate (**RWCS)

During the dewatering cycle the RWCS of the growing medium adversely affected the water status of the cedar plants of the Atlas of the four provenances. It also made it possible to define the thresholds of their resistance to severe hydric stress, particularly after 42 days of dewatering. In fact, the evolution of the TER of the substrates at the container level was affected in a very highly significant way (p <0.0001) by the type of substrate and the treatment (irrigated or stressed) (Table 2). Table 3 and Figure 2 show that the basaltic substrate has a high TER with respect to the calcareous substrate. For the controls, at the beginning of the experiment, the recorded values vary between 72.94% and 79.96% at the level of the basaltic substrate, and 41.63% and 45.6% for the calcareous substrate. After 14 days of water deficit the RWCS was 16.71% for calcareous substrate and 25.46% for basaltic substrate. Then, the values continued to decrease, reaching 2.9% and 8.02% respectively for the calcareous substrate and the basaltic substrate at the end of the dewatering cycle.

**Table 2**: Effects of substrate factors, processing and date and their interactions on the RWCS (obtained by ANOVA)

| Source* | Pr > F |
|---|---|
| Sub | <.0001 |
| Trait | <.0001 |
| Sub*Trait | 0.0004 |
| Date | 0.1544 |
| Sub*Date | 0.6865 |
| Trait*Date | 0.0988 |
| Sub*Trait*Date | 0.8229 |

* Sub=Substrate; Trait=Traitment.

**Table 3:** The means as a percentage of the relative water content followed by different letters are significantly different at a threshold of 5% according to Duncan's test.

| Number of days of stress | RWCS in % | | | |
|---|---|---|---|---|
| | Witness | | Stressed | |
| | Limestone | Basalt | Limeston | Basalte |
| 14 | 41.63 a | 79.96 a | 16.71 a | 25.46 a |
| 21 | 45.6 a | 72.94 a | 13.39 a | 20.3 b |
| 42 | 45.01 a | 77.49 a | 2.9 b | 8.02 c |

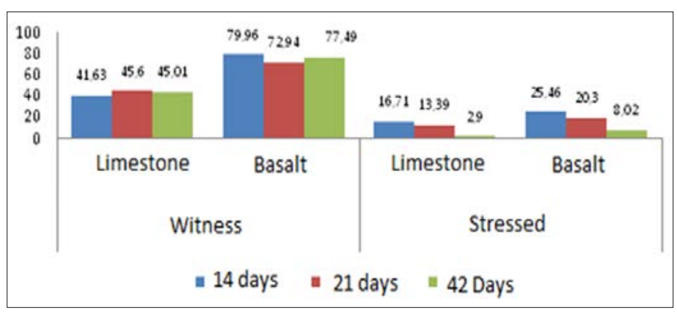


**Fig 2:** Relative water content in (%) of the two limestone and basaltic substrates during the dewatering cycle

### Basic water potential (Ψb)

The Ψb indicates the equilibrium state between the water status of the plants and the soil moisture content [19, 21]. During the water drying cycle, évolutionb evolution of the four cedar provenances is affected in a very highly significant way by the date of measurement, the source and the type of substrate. In addition, Table 4 shows that the interactions between different factors have a highly significant effect on Ψb for cedar plants.

**Table 4:** Effects of the factors studied and their interactions on the different variables measured (estimated by ANOVA).

| | PHBase | PHMidi | AMJP |
|---|---|---|---|
| **Source*** | **Pr > F** | **Pr > F** | **Pr > F** |
| Sub | <.0001 | <.0001 | 0.0017 |
| Trait | <.0001 | <.0001 | <.0001 |
| Sub*Trait | <.0001 | 0.0015 | 0.8600 |
| Date | <.0001 | <.0001 | <.0001 |
| Sub*Date | <.0001 | 0.0901 | 0.0192 |
| Trait*Date | <.0001 | <.0001 | <.0001 |
| Sub*Trait*Date | 0.0001 | 0.0107 | 0.7242 |
| Prov | <.0001 | 0.0002 | <.0001 |
| Sub*Prov | 0.0014 | 0.0434 | 0.8208 |
| Trait*Prov | 0.0018 | 0.0150 | 0.8271 |
| Sub*Trait*Prov | 0.0014 | 0.0343 | 0.1718 |
| Date*Prov | <.0001 | 0.0001 | <.0001 |
| Sub*Date*Prov | 0.2287 | 0.0321 | 0.4628 |
| Trait*Date*Prov | <.0001 | <.0001 | <.0001 |
| Sub*Trait*Date*Prov | 0.0081 | 0.0301 | 0.9556 |

* Sub=Substrate; Trait=Traitment; Prov= Source

The multiple comparison of averages performed at the end of the drying test with the Duncan test at a = 0.05, of the four provenances on the two types of substrate showed three homogeneous groups that differ significantly between them on basaltic substrate and four groups on limestone substrate (Table 5).

The evolution of the Ψb of the four provenances on the two types of substrates was affected by the application of water stress (Fig. 3). However, at the beginning of the dewatering cycle, the mean value of the Ψb (in absolute value) of the four cedar provenances does not differ significantly (Table 5). After 21 days of watering and until the end of the dewatering cycle (ie 42 days), these values show very highly significant differences for the four provenances and the two substrates. The lowest measurement (in absolute value) of the Ψb is recorded for the provenance Sidi M'guild on basaltic substrate with a value of the order of -27.81 ± 0.31bars against the values noted for the other provenances which were of the order of -32.51 ± 0.8 bars; -30.58 ± 0.52 and -30.91 ± 0.87 bar respectively for Tizi ifri, Bouadel and Tametroucht. On calcareous substrate we recorded high values for the four provenances: -34.41 ± 1.23 bars; -33.58 ± 0.52; -32.08 ± 0.38; -32.41 ± 0.62 bars, respectively for Tizi ifri, Sidi M'guild, Bouadel and Tametroucht.

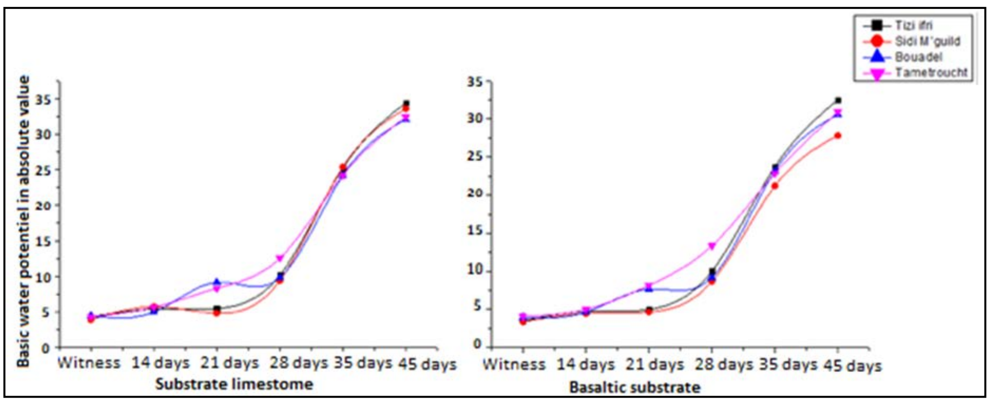


**Fig. 3:** Basic hydric potential evolution (in bar) in absolute value during the water drying cycle of the plants of four provenances of cedar planted on two substrates, limestone and basaltic

**Table 5:** The means of Ψb, Ψm and Δψw followed by different letters are significantly different at a threshold of 5% according to the Duncan test.

| Number of days of water stress | Sources | On limestone substrate | | | On basaltic substrate | | |
|---|---|---|---|---|---|---|---|
| | | **Ψb (bar)** | **ψm (bar** | **Δψw (bar)** | **Ψb (bar)** | **ψm (bar** | **Δψw (bar)** |
| Witness | Tizi ifri | 4.3±0.48 a | 15.33±0.57 a | 11.03±0.46 a | 3.5±0.5 a | 14.17±1.047 a | 10.66±1.25 a |
| | Sidi M'guild | 3.91±0.62 a | 14.55±0.5 a | 10.63±1.12 a | 3.8±0.34 a | 13.13±0.28 a | 9.78±0.62 a |
| | Bouadel | 4.46±0.64a | 16± 2 a | 11.53±1.61 a | 3.91±0.38a | 14.5± 0.86 a | 10.58±0.87 a |
| | Tametroucht | 4.33±1.04 a | 14.33±0.57 a | 10± 0.5 a | 4.08±0.8 a | 14±0.5 a | 9.91±1.28 a |
| 14 days | Tizi ifri | 5.41±0.5a | 18.91±0.38 a | 13.5±0.66 a | 4.75±0.75 a | 15.67±1.04 a | 10.91±1.42 a |
| | Sidi M'guild | 5.75±0.43a | 17.33±1.04 b | 11.58±0.8 b | 4.45±0.5 a | 16±0.5 a | 11.55±0.91 a |
| | Bouadel | 5±1.5a | 17.05±0.57 b | 12.05±1.35ab | 4.66±0.57 a | 16.66±1.25 a | 12±0.86 a |
| | Tametroucht | 5.66±0.28a | 16.33±1.04 b | 10.66±0.76 b | 5±0 a | 14.68±1.75 a | 9.66±1.75 a |
| 21 days | Tizi ifri | 5.5±0.5 b | 16.16±0.28 b | 10.66±0.76 ab | 5±1.8 b | 15.33±1.04 a | 10.33±1.04 a |
| | Sidi M'guild | 4.83±0.28 b | 16.67±1.6 ab | 11.83±1.89 a | 4.67±0.57 b | 15.31±0.76 a | 10.66±0.28 a |
| | Bouadel | 9.16±1.52 a | 17.17±0.28 ab | 8± 1.32 b | 7.66±0.28 a | 15±1 a | 7.33±0.76 b |
| | Tametroucht | 8.33±1.6 a | 18±0 b | 9.66 ± 1.6 ab | 8.16±1.04 a | 15.91±1.46 a | 7.75±0.43 b |
| 28 days | Tizi ifri | 10.16±0.8 b | 23.51±0.72 a | 13.35±1.5 a | 10±0.44 b | 22.8±0.39 a | 12.8±0.05 a |
| | Sidi M'guild | 9.4±0.3 b | 21.21±0.55 b | 11.81±0.82 ab | 8.65±0.3 c | 19.65±0.4 b | 11±0.52 a |
| | Bouadel | 9.81±0.2 b | 22.56±0.4 a | 12.75±0.68 a | 9.2±0.63 cb | 22.25±0.5 a | 13.05±1.13 a |
| | Tametroucht | 12.59±0.89 a | 22.96±0.1 a | 10.37±0.82 b | 13.36±0.87 a | 22.15±0.95 a | 8.78±1.78 b |
| 35 days | Tizi ifri | 25.23±0.57a | 28.93±1.37 a | 3.7±1.93 a | 23.71±0.48 a | 28.22±1.47 | 4.51±1.43 a |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Sidi M'guild | 25.38±1.12 a | 30.16±0.69 a | 4.78±0.93 a | 21.21±0.55b | 26.85±0.36 a | 5.63±0.41 a |
| | Bouadel | 24.18±1.03 a | 28.68±0.8 a | 4.5±1.71 a | 23.15±0.45 a | 28.53±0.6 a | 5.38±0.49 a |
| | Tametroucht | 24.23±0.8 a | 28.9±0.74 a | 4.66±1.52 a | 22.86±1.48 a | 27.78±0.49 a | 4.91±1.87 a |
| 42 days | Tizi ifri | 34.41±1.23 a | 36.15±0.36 a | 1.73±0.9 a | 32.51±0.8 a | 33.66± 0.38 a | 1.15±0.42 a |
| | Sidi M'guild | 33.58±0.52 ab | 34.98±1.35 ab | 1.4±0.83 a | 27.81±0.31 c | 29.75± 0.25 c | 1.93±0.54 a |
| | Bouadel | 32.08±0.38c | 34.07±1.24 b | 1.98±0.94 a | 30.58± 0.52 b | 32.21± 0.45 b | 1.63±0.95 a |
| | Tametroucht | 32.41±0.62 bc | 33.91±0.52 b | 1.5±0.5 a | 30.91± 0.87 b | 32.41± 1.15 b | 1.5±1.96 a |

- **Midday water potential (m)**

Ψm determines the water status of the soil and that of the evapotranspiratory demand of the air [14], during the drying cycle, it evolves in the same way as the Ψb (Fig.5) the measurement dates and the source and type of substrate affect this parameter in a very highly significant way (Table 4).

In the beginning of the experiment, the values recorded on basaltic substrate were lower than those on calcareous substrate and showing no significant difference (Table 5). The first day of measurement of the experiment was recorded respectively for the provenances of Sidi M'guild, Tametroucht, Tizi ifri, and Bouadel, on basaltic substrate -13,13 ± 0,28 bars, -14 ± 0,5 bars, -14.17 ± 1.04 bars and -14.5 ± 0.86 bars and -14.55 ± 0.5 bars, -14.33 ± 0.57 bars, -15.33 ± 0.57 bar and -16 ± 2 bars on calcareous substrate.

After 14 days of the dewatering cycle the Ψm recorded a maximum value for the Tizi ifri provenance on calcareous substrate (-18.91 ± 0.38 bar) (Fig.5). This value differentiates it from the other provenances which form a homogeneous group (-17,35 ± 1,04 bars, -17,05 ± 0,57 bars and -16,25 ± 1,04 bars) respectively for Sidi M 'provenances. Guild, Bouadel and Tametroucht. On basaltic substrate, the four provenances have a single homogeneous group with lower values than those on calcareous substrate, illustrating -15.67 ± 1.04 bars, -16 ± 0.5 bars, -16.66 ± 1.25 bars and -14.68 ± 1.75 bars respectively for Tizi Ifri, Sidi M'guild, Bouadel and Tametroucht provenances (Table 5).

At the end of the water drying test, there are three homogeneous groups of provenances that differ significantly between them on both types of substrates (Table 5). Ψma reaches its maximum on a limestone substratum with -36,15 ± 0,36 bar at the provenance of Tizi ifri having a group, followed by the Sidi M'guild provenance which presents another group with a value of -34,98 ± 1.35 bars, then the last group thus presenting provenances of Bouadel and Tametroucht with -34.07 ± 1.24 bars and -33.91 ± 0.52 bar respectively (Table 5). On basaltic substratum, there are also 3 different groups, the first from Tizi ifriqui, which has the highest value with -33.66 ± 0.38 bars, followed by the second group with provenances of Bouadel-32.21 ± 0.45 bars and Tametroucht-32.41 ± 1.15 bars and the third group of Sidi M'guild provenance with the lowest value -29.75 ± 0.25 bars.

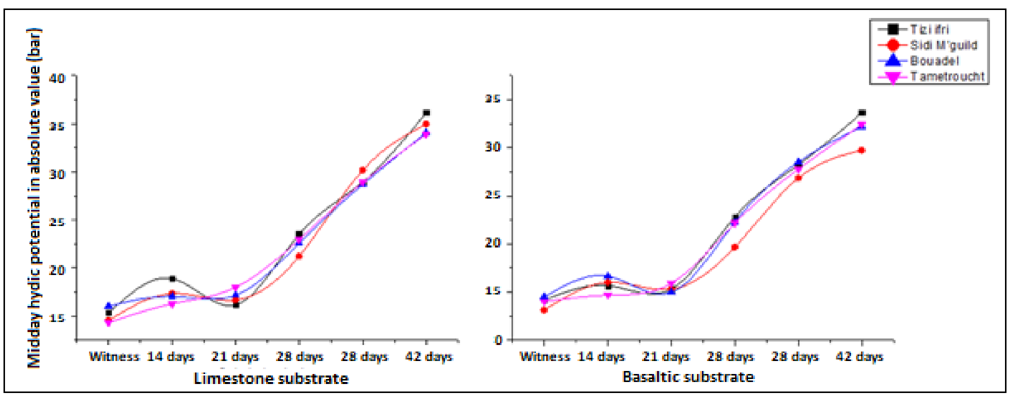


**Fig. 4:** Evolution of the midday hydric potential (in bars) in absolute value during the water drying cycle of plants of four cedar provenances planted on two limestone and basaltic substrates

- **Maximum amplitude of daily variation (Δψw)**

Δψw is the absolute value of the difference between the noon potential and the base potential. This means the variation of the water potential of a plant during the day and gives an idea of the amount of water transpired and reflects the intensity of stomatological opening [14, 20, 21]. Table 4 shows that during the water drying cycle, for the four provenances on the two substrates, the evolution of this parameter is very significantly affected by the measurement date, the source and the type of substrate. Similarly, the interactions between the different factors measured have a very strongly significant effect on Δψw.

Figure 5 shows that at the beginning of the dewatering test, the values recorded for the four provenances show no significant difference on the two types of substrates (Table 5).

After 21 days of water stress three different groups on limestone substrate. The first group presents the provenance Sidi M'guild with the value of 11.83 ± 1.89 bars, followed by the group of provenances of Tizi ifri and Bouadel respectively with values of 10.66 ± 0.76 bars and 8 ± 1, 32 bars and the third group of provenance Tamtroucht with a value of the order of 9.66 ± 1.6 bars. On basaltic substrate two different groups are recorded, one group presents the provenances of Tizi ifri and Sidi M'Guild respectively with values of the order of 10.33 ± 1.04 bars and 10.66 ± 0.28 bars, and the other group is the provenances Bouadel and Tamtroucht with the following values 7.33 ± 0.76 bars and 7.75 ± 0.43 bars (Table 5).

After 35 days of drought, on calcareous substrate the values of the Δψw from Sidi M'guild, Bouadel and Tamtroucht provenances are almost identical ranging from 4.5 to 4.78 bars. That of the provenance Tizi Ifri is equal to 3.7 bars. On the other hand, on basaltic substrate, the values of the four provenances are higher than 4 bars without exceeding 5.6 bars.

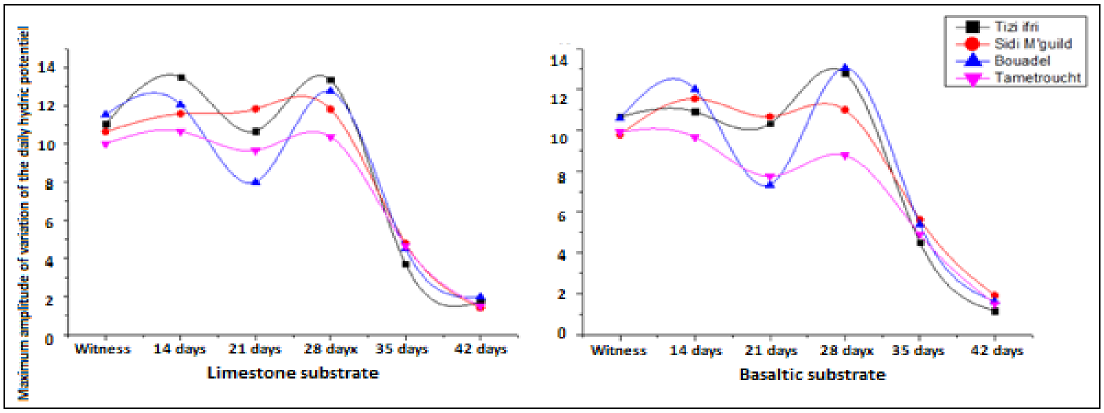


**Fig. 5:** Evolution of the maximum amplitude of daily variation of the water potential during the water drying cycle of plants of four cedar provenances planted on two limestone and basaltic substrates.

- **Critical water potential (ψc)**

Figure 6 shows that at the end of the drying cycle the values of Δψ w are less than 4 bar, the estimate of ψc (in absolute value) revealed that this parameter was on basaltic substrate lower for the four from limestone (-32.51, -27.81, -30.58 and -30.91 bars on basalt and -34.41, -33.58, -32.08 and -32.41 bars on limestone) respectively in the plants of the provenances of TiziIfri, Sidi M'guild, Bouadel and Tametroucht. Thus, the ψc of the provenance of Tizi ifri was the highest that the other provenances on the two types of substrates, that of the provenance of Sidi M'guild is the lowest on basaltic substrate.

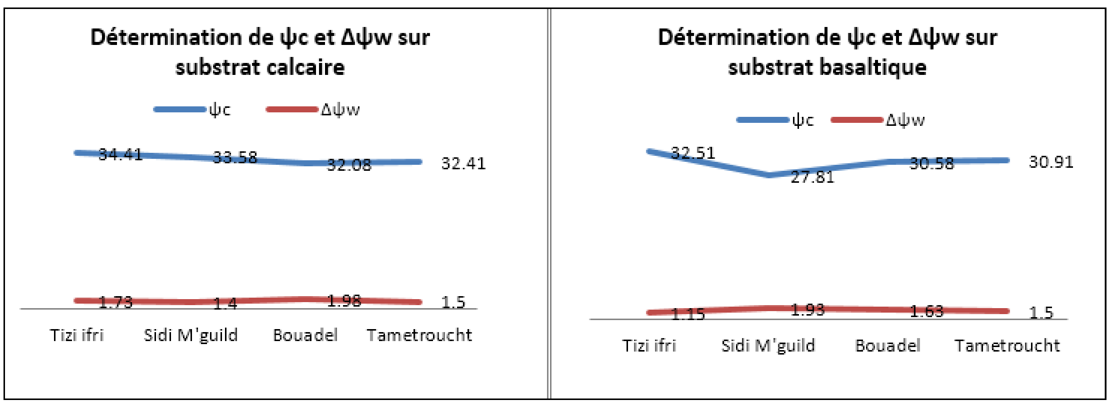


**Fig 6:** Determination of the critical base water potential and the maximum daily variation of the water potential of the four provenances of cedar plants on calcareous and basaltic substrates.

## 3. Discussion

The results obtained show clear differences in the edaphic water deficit levels of the two limestone and basaltic substrates, corresponding to the water status of the four cedar provenances of the atlas, but in a more pronounced way on the calcareous substratum compared to to the basaltic substrate. These results are in agreement with those of Lepoutre (1960) [22], Lecompte and Lepoutre (1975) [23] who reported that the physical properties of the substrates and their meso or microclimatic environment are a determining factor in the success of the species. Aadel (2006) [20] and Aoujdad *et al.*, (2018) [24] in turn indicated that the basaltic substrate is estimated by its physicochemical properties favorable to the growth and development of Atlas cedar.

Lecompte and Lepoutre (1975) [23] added that basaltic soils contain allophanes that are characterized by their moisture content in the double. Indeed, when basalt changes, it gives allophanes that retain a lot of water especially when they are associated with humic substances, which gives the soil a better structure where there is a good water retention and also good ventilation. These characteristics have been confirmed by Aoujdad *et al.*, (2018) [24] who showed that the basaltic substrate has good aeration and water retention capacity than the calcareous substrate.

The results also showed that, at the beginning of the dewatering cycle, the water reserves are satisfactory in both types of substrates, which explains the similarity of the water status and the behavior of the four cedar provenances. The observed dub values are of the order of -3.5 bar, -3.8 bar, -3.91 bars and -4.08 bar) on the basaltic substrate and (-4.3 bar, 91 bars, -4.46 bars and -4.33 bars) on limestone substrate respectively for Tizi ifri, Sidi M'guild, Bouadel and

Tametroucht. These values are close to those in nurseries reported by Aadel (2006) [20] for cedar plants -2.20 bars on basaltic substrate and -2.45 bars on calcareous substrate, and that of Zine El Abidine *et al.,* (2016) [14] which are of the order of -5.83 bars. For other softwoods, Aussenac and Granier (1978) [19] have shown that in a natural environment, for well-fed soil, the Ψb varies from -2 bars to -4 bars in Douglas fir and -4.9 bars at *Larix laricina*. Pierpoint (1967) [25] determined -4.2 bars at Piceaglauca, and -2 bars at *Abies procera*. In 1973 Hinckley and Ritchie [26] recorded -2 bars at Abies amabilis and -1 bar at *Pinus contorta* and in 1971 Wagoner and Turner [27] determined -2 bars at *Pinus resinosa*.

During the period of the dewatering cycle, the water supply potential of the plants depends mainly on the water reserves and the importance of evapotranspiration. This determines the status of the influenced water status of plants from all cedar provenances on both substrates but more importantly on calcareous substrate. Sucoff (1972) [28] showed in Pinus resinosa that there was a close relationship between the soil moisture content and the Ψb. In 1978, Aussenac and Granier [19] determined that the Ψb is used to evaluate the availability of soil water at a given time and that the fall of this parameter describes the useful water loss of the soil prospected by the roots.

The measurements made in our study show that the values of this factor have increased as a function of the number of stress days to reach, at the end of the cycle, higher levels on calcareous substrate (-34.41bars, -33.58 bars, -32.08 bars, -32.41 bars) than on basaltic substrate (-32.51 bars, -27.81 bars, -30.58 bars, -30.91 bars) respectively for provenances Tizi ifri, Sidi M Guild, Bouadel and Tamteroucht. These results are in agreement with Aussenac (1984) [29] who showed that the Ψb of cedar plants grown in pots that can withstand drying reaches -40 bars. According to Aadel (2006) [20] one-year-old atlas cedar plants reached -32.25 and -37.38 bar respectively for basaltic and limestone substrate due to increased drought. Zine El Abidine *et al.,* (2016) [14] showed that in the nursery the Ψb for cedar seedlings of the year atlas reaches -24.67 bars after 30 days of dewatering.

Concerning the Ψm, the values we recorded at the beginning of the water stress cycle on basaltic substrate are of the order of (-13,13 bars, -14 bars, -14,17 bars and -14,5 bars) and on limestone substrate (-14.55 bars, -14.33 bars, -15.33 bars and -16 bars) respectively for the provenances of Sidi M'guild, Tametroucht, Tizi ifri, and Bouadel. The same result is presented by Aadel (2006) [20], who determined that the Ψm of cedar seedlings in nursery on basalt, is of the order of -10.63 bars and -9.89 bars on calcareous substrate. As for Zine El Abidine *et al.,* (2016) [14] reported that Ψm in uncontrolled cedar plants in the Atlas is -12.42 and -9.08 bars in Atlas cypress plants. For other species in the wild, Aussenac and Granier (1978) [19] recorded on irrigated trees values of -23.5 bars in *Pseudotsuga menziesii*, -18 bar in *Abies nordmanniana*, -13.5 bar in *Picea abies*, - 11.5 bars at *Pinus nigra* et -9 bar at *Pinus sylvestris*.

At the end of the water stress cycle, the Ψm reached its maximum on calcareous substrate with (-36.15 bar, -34.98 bar, -34.07 bar and -33.91 bars) and on basaltic substrate with (- 33.66 bars, -29.75 bars, -32.21 bars and -32.41 bars) respectively in the provenances of Tizi Ifri, Sidi M'guild, Bouadel and Tametroucht. These results are consistent with those of Aadel (2006) [20] who showed that, following a water constraint, the Ψm of the cedar plants of the atlas can reach -32.13 bars on basaltic substrate and -38.13 bars on calcareous substrate. Zine El Abidine *et al.,* (2016) [14] reported that, under 30-day water stress, Ψm atlas cedar seedlings and Atlas cypress nursery trees, respectively, are in the order of -28 and -53.83 bars. In the natural environment, Atlas cedar trees recorded very low dum values of -39 bar [30]. For other species, the last authors reported -38 bar for *Quercus ilex*, -37 bars for *Pinus halepensis*, -33 bars for *Acer aquifolium* and *Quercus pubescens*, -23 bars for *Pinus sylvestris* and -22 bar for *Pinus nigra*.

The cedar plants from the four provenances showed high Δψw au values at the beginning of the cycle. After 35 days of water stress the values of Δψw are higher than 4 bars and not exceeding 5.6 bars for all provenances on the basalt, on the other hand on limestone that of the provenance Tizi ifri is equal to 3.7 bars (lower at 4) and those of other provenances are almost identical ranging from 4.5 bars to 4.78 bars. These results are consistent with those found by Aadel (2006) [20] who showed that after 35 days of drought cedar plants record a Δψw of 4.88 bars on basaltic substrate and 3.5 bars on limestone. After 42 days of water stress, the Δψw values of the seedlings from the four provenances are very low and do not exceed 2 bars on both basaltic and calcareous substrates. Note that it is the water content of the substrates at the container level which is the main limiting factor of the stomatal opening. Indeed, in the natural environment, Δψw for irrigated trees is greater than that of trees subjected to drought [19]. Thus, as the degree of soil desiccation increases, transpiration decreases and Δψw decreases and tends to zero.

Moreover, the representation of ψb as a function of Δψw makes it possible to find the critical base potential ψc where closure of the stomata is total [19]. Respectively for the plants of the four provenances Tizi ifri, Sidi M'guild, Bouadel and Tametroucht, we noted for the ψc -32,51 bars, -27,81 bars, -30,58 bars, -30,91 bars on substrate basaltic and -34.41bar, -33.58 bar, -32.08 bar, -32.41 bar on calcareous substrate. As shown by some previous work, the values in the natural environment of ψc are very variable according to the species, according to Aussenac and Valette, (1982) [30] *Quercus ilex* presente -34 bars, -33 bars for *Quercus pubescens*, -17 bars for *Pinus pinaster*, -16.5 bars for *Pinus uncinata* and -16 bars for *Quercus sylvestris*. In the nursery, Aadel (2006) [20] showed that the cedar plant peutc can reach -39 bars and Zine El Abidine *et al.,* (2016) [14] showed that ψc was of the order of -29 in Atlas cedar and -55.5 bars in Atlas cypress. Aussenac and Granier (1978) [19] also reported that cedar reached this critical value at drying levels between -30 and -35 bars.

## 4. Conclusion

From the results, it can be deduced that, under conditions of water stress, significant differences exist between the plants of the four provenances and that their behavior with respect to water stress differs. The maximum values of the different variables measured for each source on the two substrates make it possible to compare their degree of adaptation to drought. Thus, whatever the basic potential, the provenance Tizi ifri is the one most affected by drought. In contrast, the source Sidi

M'guild has the best drought tolerant behavior on basaltic substrate taking all the parameters considered. The other two provenances Bouadel and Tametroucht have values close to the parameters measured on the two substrates, exceeding that of the Sidi M'guild provenance on limestone substrate.

ConclusionThe provenance Sidi M'guild on basaltic substrate and the provenances Bouadel and Tamtrouchet on limestone show an ability to maintain the water in the tissues by limiting transpiration losses and therefore appear to be more water-conserving than the origin of Tizi ifri.

Similarly, the ecophysiological analysis of the four provenances on the two substrates shows differences in behavior between the provenances of the Middle Eastern Atlas, Central Middle Atlas and the Eastern High Atlas of the Rif provenance. The plants of this latter origin seem to be shifted from those of the other three provenances.

Moreover, this comparative study makes it possible to provide information on the behavior of provenances and their threshold of tolerance to water stress, but the results can be refined after further research on other characteristics, in particular the functioning and development of, photosynthesis, transpiration, stomatal conductance and root apparatus.

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