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# Is the Decline in Rainfall the Main Cause of Selective Mortality of Pterocarpus Lucens in Northern Burkina Faso?

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## ABSTRACT

**Introduction:** *Pterocarpus lucens* has ecological and socio-economic importance for arid and semi-arid zone of West Africa. Unfortunately, in recent decades its selective mortality has been noted in sub-Sahelian zone. Declining of groundwater levels, anthropogenic pressure on species and termites are cited as causes. Although these natural and anthropogenic disturbances seem pertinences, this study aimed to analyze intrinsic physiological responses of this species to adapt to its environment condition that is becoming increasingly arid.

**Materials & Methods:** Leaves water potential (Ψ) with its attributes (predawn water potential (Ψb), midday water potential (Ψm) and the range (ΔΨ) between (Ψb) and (Ψm)) were measured in two sites with contrasted water conditions using pressure chamber. Complementary variable such as water content (WC) and water relative content (RWC) were measured and analyzed.

**Results:** Results showed that Midday and predawn water potential were significantly lowest ($P < 0.001$) in Dori than Tougoury and diurnal range of individual shrubs in Dori showed no significant relaxation ($P > 0.05$).

**Conclusion:** These results suggest that the species is experiencing unfavorable water conditions at the Dori site and could partly explain its selective mortality. Further studies will be necessary to determine other factors and their impact on the phenomenon.

**Key Words:** Water potential, Water stress, Climate change, *Pterocarpus lucens*, Adaptation of plants, Burkina Faso.

## INTRODUCTION

The leaves and fruits of *Pterocarpus lucens* are excellent fodder for livestock, but grazing generally decreases between the dry season and the rainy season, except for goats and camels, whose grazed fodder can account for up to 80% of their diet.[1,2] As any other forage, *P. lucens* leaves provide an essential complement of nitrogen for livestock in the late dry season to digest dry grass cellulose. Indeed, a review revealed a N-concentration in woody fodder plants to be the range of 16-33 g $kg^{-1}$.[2] Furthermore, it has been established that leaves and pods of *P. lucens* had high protein content and good intake characteristics with high nutrient digestibility for goats.[3] *P. lucens* leaves are regularly sold in markets (for instance 95-298 F $kg^{-1}$ in Mali) for stall feeding of livestock in urban and peri-urban areas.[2] Leaves are also used for human consumption in several counties of Burkina Faso (provinces of Kossi and Yatenga). Energetically, *P. lucens* is a good firewood, charcoal and craft wood.[4,5,6] All parts (wood, roots, bark, stems and leaves) of the tree used in pharmacopoeia as an antibiotic and analgesic. It is a species of bee and the only papilionaceous tree in the Sahelian zone that forms a dense forest.[4]

Despite its ecological and socio-economic importance, we are witnessing in recent decades selective mortality of this species, which forms wood cemeteries that are spreading southward, thus endangering its sustainability.[4,5,7,8] *P. lucens* trees are cluttered with dead wood and are between life and death. Mortality rates of this species of up to 60% in Sahelian zone, 28 to 36% in Titoa area [4], 47% in Taparko [5] have been observed for this species. The rate of decline, calculated as the difference between the renewal rate and the mortality rate, was -59%.[4] This high level mortality accelerates the desertification process, causing loss of valuable forest genetic resources, destroying productive resources basis, increasing

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atmospheric dust, disrupting natural recycling process of waters and disrupting family and even national economies.[5] Lowering groundwater levels, human pressure, and termites have often been cited as the main drivers.[14] If anthropogenic disturbances and termite attacks are easy to understand, the physiological responses of this species to the increasing arid environmental conditions remain largely uninvestigated. Droughts are often accompanied with high temperature and have negative impact on tree growth and survival.[9] Understanding how this species strives to adapt to the new conditions has some management implications with the aim to reduce the high mortality.

In the context of the present study, adaptation refers to changes in structure or function heritable, which increase the fitness of the organism in a stressful environment.[10] The capacity of plants to respond and cope with water deficit caused by drought depends on the mechanisms or strategies developed to adapt to the environmental conditions.[11] The water deficit can be defined as the internal water status that limits production of dry matter of a vegetal species during a given period of its development cycle. Drought does not always cause stress or water deficit in plants as they can respond to it by implementing adaptive mechanisms that allow them either to avoid or to tolerate it without a significant reduction of yield.[12]

Water stress in plants is generally determined through direct measurements of three essential parameters: water potential, water content and relative water content. Water potential is an intensive thermodynamic quantity that determines the direction of the exchanges of water between two points of the set formed by soil, vegetation and atmosphere.[13,14] It is a good indicator of the physiological state of the plant, because photosynthesis, cell elongation, stomatal opening are strongly influenced by it.[15,16] Furthermore, it incorporates soil water availability, climatic constraints and the intrinsic response of species to water stress.[17] Particular attention is generally given to predawn water potential, midday water potential and diurnal range of water potential. Predawn water potential ($\Psi b$) is measured when transpiration is virtually at zero. It indicates soil water potential in rhizosphere zone.[17,18,19] This parameter provides some information on the edaphic component of water stress supported by plants. In the night, plants balance their water potential with their rhizosphere zone soil humidity. Accordingly, decrease of water availability in these horizons generally results in lower predawn water potential towards more negative values. Midday water potential ($\Psi m$) obtained at noon shows the maximum internal water deficit of the plant. It also provides information on the existing tension in the xylem sap during transpiration, which depends in particular on the tension of the water in the soil, the intensity of transpiration, hydraulic conductance of the soil-plant-atmosphere system. Low midday water potential provides information on the capacity of the plant to adapt to its environment because of its capacity to lower their water potential.[18,20] From the two variables (predawn water potential and midday water potential) diurnal range of the water potential is calculated using the following formula: $\Delta\Psi = \Psi b - \Psi m$. This variable indicates the daily relaxation and is wide with plant of large ecological distribution zone.[18] Another of important variable for plant adaptation to environmental conditions is relative water content of leaves. Leaves relative water content (RWC) is the mass of water contained in leaves sample at the time of harvest compared to the mass of water contained in the sample at full turgor. Species that maintain high RWC are considered to be drought-resistant species.[21]

Using all of the above plant adaptation variables, the objective of this study is to analyse the physiological responses of *P. lucens* in two different environmental conditions within its range in Burkina Faso.

## METHODOLOGY

Study was carried in Dori and Tougouri (Figure 1). The Dori site (N13 59 25.0 W0 01 41.6) is located in Sahelian zone (Figure 2A) where rainfall is less than 600 mm with a wet season that goes for 3 months., Tougouri site (N13 19 07.1 W0 30 57.0) is located in sub-sahelian climate zone where wet season is about 4 months with rainfall mean of 600±150 mm (Figure 2B)

The soils in Dori are halomorphic with a degraded structure: solonetz on sandy-clay material, slightly leached and leached tropical ferruginous soils on sandy, sandy-clay, and clay-sandy materials, and eutrophic tropical brown soils on clay materials. In Tougouri, the soils are poorly leached and leached tropical ferruginous soils on sandy, sandy-clay, and clay-sand materials, and poorly evolved erosion soils on gravelly material.

The two sites of Dori and Tougouri are relatively flat, with average altitudes of 280±2 m and 281±3 m, respectively.

For each species, six representative individuals of *P. lucens* were selected at random. However, those located in wetlands (riparian areas and shallows) were avoided. On each of the selected trees, the measurement was repeated five times, i.e., on five leaves. Coordinates of each plant were recorded using a Garmin GPS60, Taiwan. Then morphological attributes such as diameter and height were measured as well as some physiological parameters. Height was estimated with a clinometer while diameter (D) was deduced from the circumference (C) measured with tape (precision 0.5 cm) by the following formula:

$$D = \frac{C}{\pi}$$

with $\pi = 3.14$

On average, sample trees displayed 25 cm in diameter and 4 m in height in Dori whereas the values of the same variables were 14 cm and 2 m in Tougouri, respectively. In December (study period), plants in Dori, the specy trees presented an advanced defoliation.

### Measured variables

Measured variables were leaf water potential (predawn water potential and midday water potential and calculated) in MPa, leaves water content (WC), and relative leaves water content (RWC) as a percentage (%). Based on predawn and midday water potential values diurnal range of water potential in MPa was calculated. Measurements were carried in December, during dry season, before leaves shedding of several tree species. They were carried out at a time of day when the water potential of plants is relatively stable, i.e. at dawn and midday.[18,22,23]

To measure water potential, we used the method and procedure described by [20,31], which involves using a pressure bomb to measure the sap pressure in the petiole of a leaf (Figure 3). The measurements were taken using a Style V2 pressure chamber (known as a Scholander chamber) equipped with a compressed air source, a flow regulator, and a DIN KL 0.6 Skalenwert precision pressure gauge (0.05 MPa) (Figure 3). For predawn water potential, one leaf per plant was taken just before the measurements by breaking the stalk at its insertion on the node. The petiole was cut from its end with a sharp "cutter" in order to avoid that the tissues crush. It was then introduced into the hole of the lid of the pressure chamber. A seal was placed around the petiole using flexible rubber and the leaf placed in the chamber. The chamber was pressurized gradually and the value of water potential noted when the exudation at the section of the petiole appeared. This value corresponds to the pressure in the chamber displayed by the gauge. Predawn water potential's measurements were made at dawn, between 3:30 am to 6 am. Those of midday water potential were made at noon, between 11 h 30 and 15 h. For measurements at midday, leaves were collected in the portion of the plant which is the most exposed to sunlight and considered to have maximum water stress.[18] Samples used for measurements were taken from branch at almost the same height for all the studied trees.

For water content, some leaves from the same branch as those used to measure water potential were harvested, immediately wrapped in paper envelopes, and weighed fresh (FW1) on a scale PESSOLA ® with precision 0.1 g. The samples were then dried in an oven at 80°C for 24 h. The dry weight of the sample (DW) was measured using the same balance. The water content ($WC_d$) is related to the dry matter and determined using the following formula:

$$WC_d = \frac{\left(\left(FW1 - DW\right)*100\right)}{DW}$$

Other leaves from the same branch as those used to measure water potential were removed and soaked in a 15-liter bucket filled three-quarters full with water. The device was completely covered by a dark plastic bag and kept in the shade in a house for 24 h. Thereafter, water-soaked leaves were removed and packed in paper envelopes and immediately weighed using the scales PESSOLA ® with Precision 0.1 g. Resulting weight was called saturation or turgor weight (SW). Saturated sheets were then dried in an oven until constant weight and reweighed. That was called dry matter weight (DW). Fresh matter weight (FW2) was obtained here by extrapolation.

$$MF2 = MS * X$$

with X equal to the proportion of fresh material from the dry matter in the sample used to measure the $WC_d$

$$X = \frac{MF1}{MS1}$$

The relative water content (RWC) is obtained by the following formula:

$$RWC = \frac{\left(FW2 - DW\right)*100}{SW - DW}$$

### Data analysis

For data analysis, Shapiro test (normality) and Bartlett test (homogeneity) of the variance were initially checked. Then, the differences in variation of predawn water potential, midday water potential, diurnal range of water potential, water content and relative water content between the sites were determined using analysis of variance (ANOVA) with XLSTAT Pro 7.5 software. Further, the separation of the means was performed using Tukey test, when the P value was significant. The significance threshold was of 5%.

Pair-wise mean comparisons of midday water potential and predawn water potential values were carried out in order to evaluate the range of daily relaxation of each species.

Subsequently, midday and predawn values were used respectively as Y and X axes on an orthonormal mark. A 45° diagonal line was plotted on the graph for each species. The bisecting line is the boundary where both midday and predawn water potential have equal values. It represents permanent wilting point for the plant, in other word, the limit were no water uptake was possible. So more points or trend line was far from the bisecting line, the higher significant the range of daily relaxation was.[18,23,24]

## RESULTS

Midday water potential (-5.8±0.5 MPa) and predawn water potential (-4.9±0.8 MPa) displayed in Dori site were highly significantly (P <0.001) lower compared to those at the Tougouri site where Midday water potential and predawn one were respectively -4.3±0.5 MPa and -1.7±0.5 MPa. As a result, the greatest amplitude of diurnal water potential (2.6±0.6 MPa) was recorded in Tougouri, compared to only 0.9±0.8 MPa at the Dori site (Table 1).

Tukey test implemented made on diurnal range of individual shrubs shows no significant relaxation (P> 0.05) for shrubs located in Dori. However, relaxations for shrubs in Tougouri were very highly significant (P < 0.001).

*P. lucens* has lower and non-significant daily relaxation in Dori given that points on this site are very close to the diagonal compared to those on Tougouri (Figure 4).

Shrubs water content (119.3%) and relative water content (63.0%) at Tougouri site were significantly higher (P < 0.01) than those observed at Dori, which were 72.2% and 34.8% respectively for water content and relative water content (Table 1).

## DISCUSSION

The Difference in predawn water potential of *P. lucens* between Dori and Tougouri means that this species' access to water also differs between these two locations. Hydrological conditions are more favourable in Tougouri, which receives more rainfall. These favourable soil water conditions are reflected in the higher pre-dawn water potential measured at this site.

The lower water potential observed at midday in Dori suggests that plants are more stressed at this site than in Tougouri. The value of this parameter in Tougouri (-4.30 MPa) is similar to that observed (-4.31 MPa) by [5] for the same species in Tapargo.

The larger variation in water potential of *P. lucens* in Tougouri compared to Dori constitutes an indication of its better adaptation to the first site corroborating. [20]

*P. lucens* presented a non-significant range of water potential in Dori. This result suggested that this species is no longer adapted physiologically to Dori site. This could explain high selective mortality of this species reported by. [5,7] It begins losing its leaves in December to cope with drought by avoidance strategy. In December (study period), plants in Dori presented an advanced defoliation suggesting that they adopted an effective survival mechanism via leaf shedding only two months after the rainy season.[9] Plants mortality could be explained by its inability to keep intact its internal structures against cavitation given the intensification of aridity in recent decades in the Sahel region. Indeed, the survival of plants subjected to drought depends on their ability to maintain their internal structures intact and to prevent their vascular system against cavitation and embolism until favorable season.[25,26]

*Pterocarpus lencens* stand is unstable in Dori due to the high mortality rate of juveniles of this species.[27] Indeed, rooting is positively correlated with plant diameter.[28] Adverse water conditions in Dori could explain like of young plants because they are more sensitive to water stress. Indeed for *Pterocarpus lucens*, absorption of water and nutrients in the dry season is done through taproots and root hairs, while the first meter depth where fall roots is dried up during nine months per year in dry season.[28,29] However, the water potential could be positively influenced by the existence of microclimates even in environments with very difficult water conditions.[24,30] All planting activities of this species should therefore target these areas with favorable water conditions. Nevertheless, it would be necessary to conduct additional socio-economic research to determine other factors, particularly anthropogenic ones, and the extent of their impact on soil water conditions at both sites. This would contribute to the success of any efforts to restore the population of this species in this arid part of the country.

## CONCLUSION

The objective of this study was to analyse the physiological responses of *P. lucens* in two different environmental conditions within its range in Burkina Faso. The results show that the water potential at midday and before dawn was significantly lower in Dori than in Tougouri and that the diurnal amplitude of individual shrubs in Dori shows no significant relaxation. These results suggest that the species is experiencing unfavorable water conditions at the Dori site. However, the water potential could be positively influenced by the existence of microclimates even in environments with very difficult water conditions. All planting activities of this species should therefore target these areas with favorable water conditions. Nevertheless, further socio-economic research would be necessary to determine other factors, particularly anthropogenic ones, and the extent of their impact on soil water conditions at both sites. This would contribute to the success of any initiative aimed at restoring the population of this species in this arid region of the country.

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## Conflict of Interest

All authors declare no conflict of interest

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## Authors' contribution

KJ conceptualized and designed the study, coordinated data collection, and interpreted the results. DS and SL participated in reading of the manuscript. SL reviewed and read the final manuscript.

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Table 1: Pterocarpus lucens *physiological parameters in Dori and Tougouri in Burkina Faso*

| | MWP (MPa) | PWP (MPa) | DRWP (MPa) | WC (%) | RWC (%) |
|---|---|---|---|---|---|
| DORI | -5.8 ± 0.5 a | -4.9 ± 0.8 a | 0.9±0.8 b | 72.2 b | 34.8 b |
| TOUGOURI | -4.3 ± 0.5 b | -1.7 ± 0.5 b | 2.6±0.6 a | 119.3 a | 63.0 a |
| P-value | <0.001 | <0.001 | 0.002 | 0.002 | 0.007 |

**MWP**= Midday water potential; **PWP**= Predawn water potential; **DRWP**= Diurnal range of water potential ; **WC**= Water content; **RWC**=Relative water content. Scholander PF, Bradstreet ED, Hemmingsen EA, Hammel HT. Sap pressure in vascular plants: negative hydrostatic pressure can be measured in plants. Science. 1965; 148(3668): 339-346. doi:10.1126/science.148.3668.339.

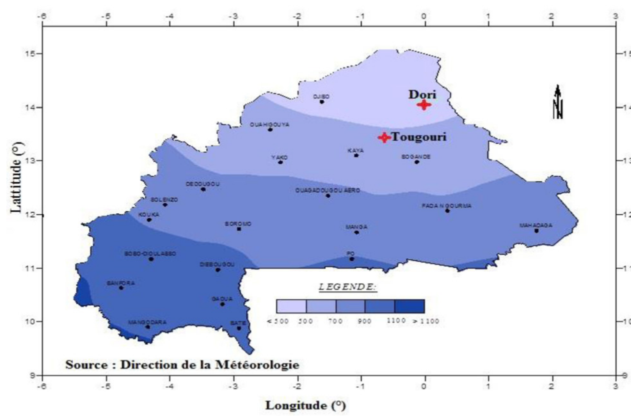


**Figure 1:** Location of Dori and Tougouri in isohyets map of Burkina Faso (Adapted from Direction of the National Meteorology)

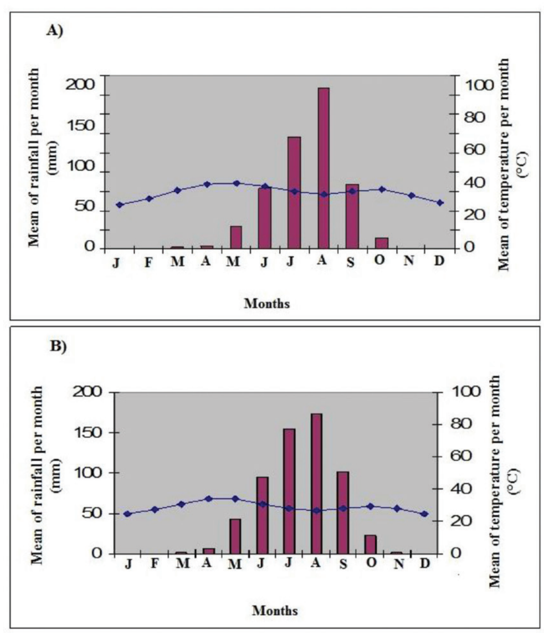


**Figure 2:** Umbrothermal curves for study sites: Dori and Tougouri

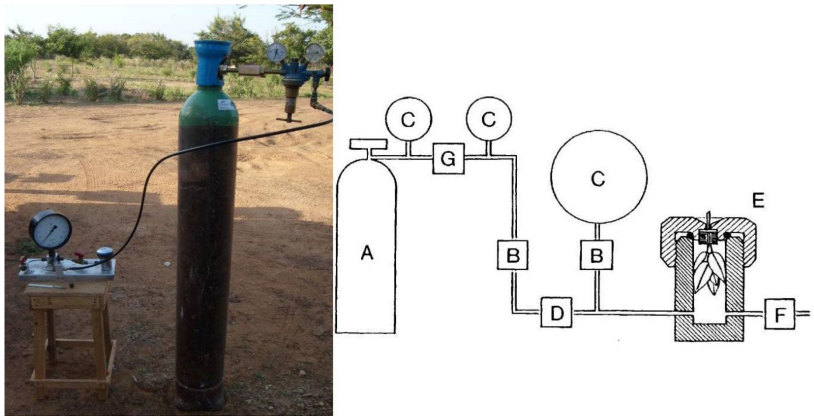


**Figure 3:** Photo and schema of pressure chamber.[20,31] A- gaz bottle ; B- Air transmission valve ; G- Air control valve et D- Adjusting valve ; F- Exhaust valve ; C- Manometer indicating pressure level ; E- Pressure chamber (*Photo Koala Jonas*)

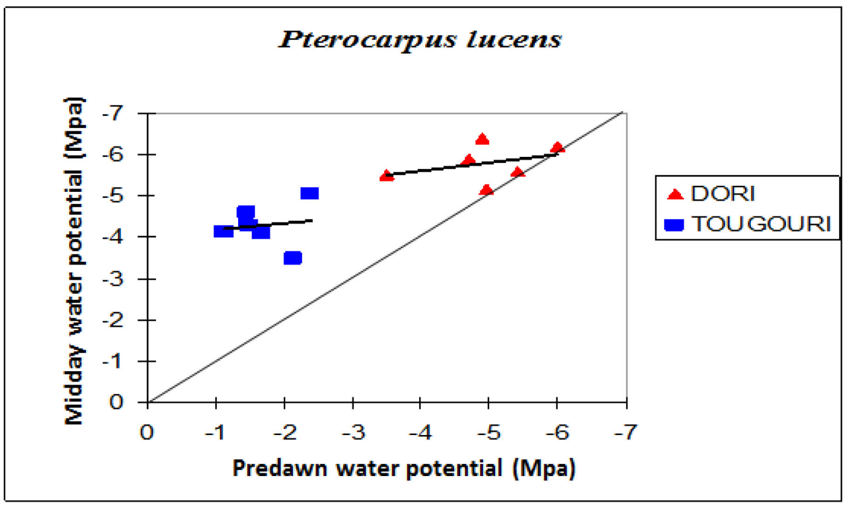


**Figure 4:** Expression of predawn water potential in relation to midday water potential of *Pterocarpus lucens* in Dori and Tougouri in Burkina Faso