TREE-RING BULLETIN, *Vol. 47, 1987*

THE SUMMARY RESPONSE FUNCTION OF *CEDRUS ATLANTICA* (ENDL.) CARRIERE IN MOROCCO

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ABSTRACT

This paper presents the synthesis of all the response functions computed on *Cedrus atlantica* (Endl.) Carrière in Morocco. More than a thousand tree-ring width series collected in 40 sites have been used. At every site, a distinction has been made between young adult trees and old adult trees. Response functions have been calculated on the mean raw ring widths by using the multiple linear regression model of Guiot (Guiot *et al.* 1982). Among the variables selected to determine the response of *Cedrus* to climate, the precipitation of autumn and winter and the temperature of January, April, August and September play the leading part in explaining the ring-width variations.

Der Beitrag enthält eine Synthese aller für Cedrus atlantica in Marokko berechneten Response Funktionen. Dafür wurden mehr als tausend Jahrringfolgen von 40 Standorten benutzt. Pro Standort wurde unterschieden in junge, aber erwachsene und in alte Bäume. Die Response Funktionen wurden auf der Grundlage der mittleren Jahrringbreite mit Hilfe des multiplen linearen Regressions-modells von Guiot (Guiot *et al.* 1982) erstellt. Von allen Variablen zur Beschreibung der Klima-Wachstums-Beziehungen von Cedrus tragen die Herbst- und Winterniederschläge sowie die Temperatur im Januar, April, August und September am meisten zur Jahrringbreitenvariation bei.

Cet article présente la synthèse des fonctions de réponse calculées sur le Cèdre de l'Atlas (*Cedrus atlantica* (Endl.) Carrière) au Maroc. Plus de mille chronologies de cernes réparties en 40 sites ont été utilisées. Dans chaque site, une distinction a été réalisée entre les arbres au stade jeune adulte et les arbres au stade vieil adulte. Les fonctions de réponse ont été calculées sur les épaisseurs brutes des cernes à l'aide du modèle régressif linéaire de Guiot (Guiot *et al.* 1982). Parmi les variables choisies pour déterminer la réponse du Cèdre au climat, les précipitations d'automne et d'hiver ainsi que les températures de janvier, d'avril, d'août et de septembre influencent le plus les variations de l'épaisseur des cernes.

INTRODUCTION

Characterized by sunny, hot and dry summers and sometimes by dry winters too (Till 1985), the Mediterranean area is a very sensitive region where some tree species, strongly affected by water stress are particularly favourable for dendrochronological studies. Such studies are badly needed to provide paleoclimatic information in countries which often know drought problems, such as those in Northern Africa.

Among all the dendrochronological works carried out in the Mediterranean basin (as stated by Munaut (1982) and Serre-Bachet (1985)), the study of *Cedrus atlantica* (Endl.) Carrière in Morocco initiated a few years ago by Professor A. V. Munaut, constitutes the first dendrochronological research undertaken on a wide scale in order to furnish ecological information about the effect of climate on the growth of a forest species and its ability to provide paleoclimatic information. Till now, the published papers concerning this study were focused on methodological questions and mathematical procedures (Munaut *et al.* 1978, Berger *et al.* 1979, Guiot 1981, Guiot *et al.* 1982, Till 1984). The aim of this contribution is to present the summary of all the response functions computed between tree-ring width and climate for *Cedrus atlantica* in Morocco.

Morocco has a particular situation in the Mediterranean basin between 28° and 36° latitude north, 2° and 12° longitude west of Greenwich. Morocco is limited at north by the Alboran sea, at west by the Atlantic ocean, at east and south by the Sahara desert. This situation determines the climate of the country which is also influenced by the topography. The country is situated under Oceanic, Mediterranean and Saharan influences. The hot and dry summers are dependant on the seasonal shift of the high subtropical pressure, while winter rainfall is determined by the displacement of the north-west cyclonal activity. Two gradients characterize the climate of Morocco: a north-south gradient and a west-east one; along them precipitation decreases and temperature increases.

The Moroccan mountains are, from north to south, the Rif, the Middle Atlas, the High Atlas and the Anti Atlas. They are oriented along two axes, a west-east one (Rif) and a south-west north-east one (Atlas), with a maximum altitude of respectively 2,450 and 4200 m. *Cedrus* grows from about 1300 to 2600 m in the Rif, the Middle Atlas and the Eastern High Atlas. In the schematic altitudinal arrangement of species and vegetation admitted for the Mediterranean region (Quézel and Barbero 1982), *Cedrus* is mainly observed in Morocco at the Mountain-Mediterranean and Oro-Mediterranean levels but it may also be observed at the Upper-Mediterranean and Supra-Mediterranean levels (Benabid 1982). Its optimum corresponds to the Mountain-Mediterranean level (Achhal *et al.* 1980, M'Hirit 1982).

The geographical situation of the country and the topography determine in fact several bioclimatic zones (Emberger 1971, Daget 1977, Daget and David 1982). These bioclimatic zones are defined according to Emberger's pluviothermic ratio ($Q2 = 2{,}000\ P/(M^2 - m^2)$) in which P is the annual rainfall in mm, M, the mean maximum temperature of the hottest month and m, the mean minimum temperature of the coldest month. In each bioclimatic zone, it is possible to distinguish thermic variants, defined according to the values of m. The following values of Q2, P and m are generally admitted in order to define the bioclimatic zones and their thermic variants:

Bioclimatic zones	**Q2**	**P mm**
Hyperarid	< 10	< 100
Arid	10 to 45	100 to 400
Semi-arid	45 to 70	400 to 600
Subhumid	70 to 110	600 to 800
Humid	110 to 150	800 to 1200
Hyperhumid	> 150	> 1200

Thermic variants	**m °C**
icy	< -10
extremely cold	-10 to -7
very cold	-7 to -3
cold	-3 to 0
cool	0 to $+3$
temperate	$+3$ to $+4.5$
mild	$+4.5$ to $+7$
hot	$+7$ to $+10$
very hot	$> +10$

In Morocco, *Cedrus atlantica* is observed in the upper semi-arid zone to the Hyperhumid zone, cold to extremely cold variants. It has its optimum in the subhumid and humid zones, very cold variant. (Quézel 1979, Achhal *et al.* 1980, M'Hirit 1982).

TREE-RING DATA

Forty sites have been selected throughout the whole natural area of the cedar forest in Morocco to compute the response functions. At first, a distinction has been made between young adult stage trees and old adult stage trees and mean chronologies have been defined on raw ring widths (Till 1985). Figure 1 illustrates clearly the changes in rate of radial growth, the definition we give to the young adult stage and to the old adult stage. The exponential curve which fits the time-series of ring widths (1745-1978) has the equation:

$$y(t) = 518e ** (-0.035\ t) + 56$$

As the growth of a tree can be represented by a negative exponential curve, the young adult stage is the period during which the growth is decreasing rapidly (1745-1810); the old adult stage is the period during which the growth is decreasing very slowly (1810-1978).

The results of response functions presented in this paper concern only the old adult stage trees. The total time period covered by the chronologies is extending from 1016 to 1979 but only the period covered by meteorological data (1941-1970) has been used to compute response functions.

Dendrochronological parameters (Table 1) have been computed over the same period (1941-1970) with the exception of the percentage of missing rings, which is computed over the whole period covered by the chronologies. The mean sensitivity ranged between 0.08 and 0.44 shows three groups of sites:

- the complacent sites for which the mean sensitivity is lower than or equal to 0.15;
- the intermediate sites for which the mean sensitivity is comprised between 0.16 and 0.29;
- the sensitive sites for which the mean sensitivity is greater than or equal to 0.30.

There are also hypersensitive sites for which the ring-width series cannot be cross-dated and which are not included here.

Figure 2 shows how the mean sensitivity increases with the climatic gradients existing in Morocco and Figure 3 illustrates that the mean sensitivity increases somewhat with altitude as well as with distance from the sea. Pearson's correlation coefficient (r-Pearson) and Spearman's correlation coefficient (r-Spearman) measure the association between different values taken by the mean sensitivity and the altitude: r-Pearson = 0.35 and r-Spearman = 0.42; they are respectively statistically different from 0.00 at the 0.0058 and 0.0010 significance level. The mean sensitivity is also linked to the substrate: the mean sensitivity is the lowest on humid dolomitic or basaltic substrates; it is greatest on dry substrates of limestone and on substrates of marl and/or shale. There is no prominent relation between the mean sensitivity and aspect or between the mean sensitivity and slope. There are of course local variations of the relation between mean sensitivity and ecological factors.

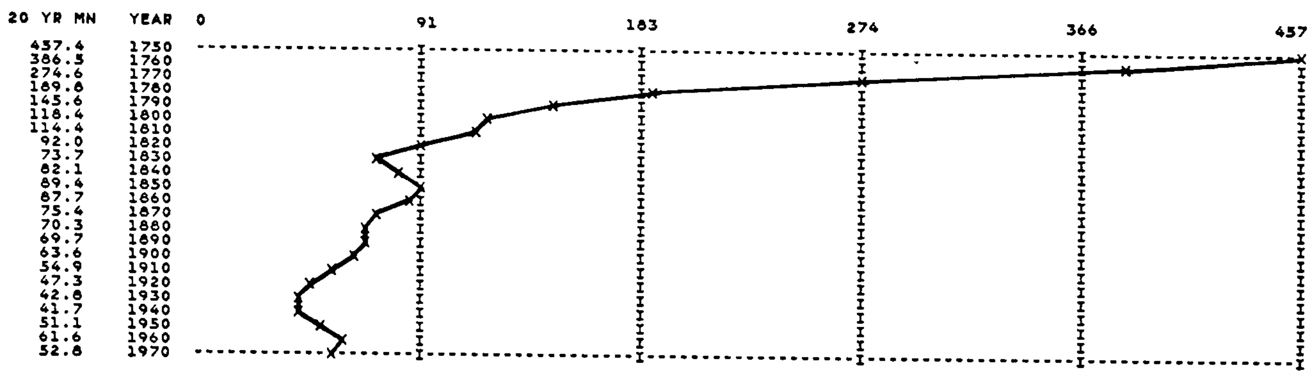

Figure 1. Morocco, *Cedrus atlantica*. The trend of declining growth with increasing age represented by 20-year means (20 YRMN) centered on the beginning of every decade (YEAR).

Table 1. Morocco, *Cedrus atlantica.* The dendrochronological parameters. csens = chronology mean sensitivity, msens = average of the mean sensitivities of individual cores, cv = coefficient of variation, anvar = percentage of variance attributed to the chronology, cabs = percentage of missing rings, cmoy = mean ring, ecty = standard deviation, caucor = first-order autocorrelation coefficient.

	Site	csens	msens	cv	anvar (%)	cabs (%)	cmoy (mm)	ecty (mm)	caucor
1	Tetla de Ketama	0.24[2]	0.31	0.24	33	0.16	1.17	0.28	0.31
2	Jbel Tidighin	0.09[1]	0.17	0.12	15	0.38	1.07	0.13	0.55
3	Tizi Mohkrane	0.11[1]	0.18	0.15	24	0.24	0.58	0.09	0.55
4	Agdir Amellal	0.36[3]	0.42	0.35	35	1.23	0.45	0.16	0.31
5	Afraskou	0.27[2]	0.35	0.29	50	1.89	0.78	0.23	0.50
6	Hayim Tirhist	0.19[2]	0.27	0.21	40	1.40	1.08	0.23	0.46
7	Mitkane	0.25[2]	0.35	0.24	40	1.29	0.66	0.16	0.26
9	Ouiouane	0.17[2]	0.24	0.18	18	0.18	1.45	0.26	0.43
10	Taffert	0.24[2]	0.35	0.23	36	0.49	0.81	0.19	0.20
11	Bouzemmour	0.20[2]	0.31	0.21	42	1.21	0.66	0.14	0.12
14	Tizi Aït Ali	0.31[3]	0.41	0.35	38	1.32	0.69	0.24	0.50
15	Gueb er Rehal	0.32[3]	0.45	0.40	29	0.99	0.52	0.21	0.59
17	Col de Zad	0.33[3]	0.46	0.33	51	1.06	0.54	0.18	0.22
19	Aguelmam Azigza	0.12[1]	0.20	0.18	22	0.11	1.76	0.32	0.65
22	Jbel Lakrâa	0.08[1]	0.15	0.13	15	0.07	1.41	0.18	0.71
23	Tamtroucht	0.21[2]	0.30	0.23	23	0.27	0.88	0.20	0.28
24	Tankararant	0.25[2]	0.36	0.29	53	0.57	0.49	0.14	0.26
26	Tizi Aïni	0.27[2]	0.34	0.24	44	0.24	0.45	0.11	0.13
27	Adrar bou Mellal	0.19[2]	0.26	0.23	32	0.77	0.66	0.15	0.46
30	Sidi M'Guid	0.28[2]	0.38	0.36	42	0.29	1.10	0.40	0.65
31	Aïn Kahla	0.19[2]	0.26	0.24	45	0.20	0.71	0.17	0.64
32	Tizi n'Tarzeft	0.34[3]	0.46	0.46	54	1.11	0.57	0.26	0.69
33	Jbel Hayan	0.22[2]	0.31	0.30	44	0.64	0.63	0.19	0.65
34	Immouzer des Marmoucha	0.30[3]	0.37	0.27	54	0.81	0.78	0.21	0.09
35	Talaharine	0.26[2]	0.34	0.37	42	1.21	0.81	0.30	0.69
36	Jbel Tanourdi	0.35[3]	0.46	0.48	52	1.09	0.64	0.31	0.78
37	Jaffar	0.33[3]	0.40	0.38	57	1.55	0.65	0.25	0.48
38	Ghomara	0.13[1]	0.25	0.21	25	0.68	1.00	0.21	0.69
39	Jbel Dahdo	0.09[1]	0.16	0.10	6	0.04	0.87	0.09	0.30
40	Tizi Ifri	0.21[2]	0.26	0.24	28	0.09	2.01	0.49	0.36
41	Ich Ramuz	0.23[2]	0.33	0.27	43	0.39	1.17	0.32	0.58
42	Jbel Serhla	0.14[1]	0.19	0.16	25	0.07	1.08	0.17	0.22
43	Es Sheb	0.15[1]	0.21	0.18	23	0.23	1.64	0.30	0.51
44	Ladmer Izem	0.23[2]	0.29	0.26	51	0.32	0.85	0.22	0.39
45	Izdi Ouareg	0.21[2]	0.31	0.29	54	0.76	0.48	0.14	0.47
46	Bekrit	0.32[3]	0.42	0.33	45	1.72	0.60	0.20	0.59
47	Jbel Irhoud	0.18[2]	0.25	0.20	21	0.85	0.97	0.19	0.21
48	Louta Zad Tafessene	0.30[3]	0.52	0.40	48	1.60	0.48	0.19	0.63
49	Bou Izane	0.44[3]	0.49	0.37	57	2.45	0.57	0.21	0.25
50	Amalou'n Moukchab	0.36[3]	0.42	0.33	48	2.46	0.98	0.32	0.25

[1]complacent site [2]intermediate site [3]sensitive site

The dendrochronological parameters are well correlated except for the standard deviation and the first-order serial correlation coefficient. The parameters are not linked to the number of samples included in the mean chronologies except for the first-order serial correlation coefficient.

Figure 4 illustrates the relation between the dendrochronological parameters as defined in Table 1. It gives a more expanded view of the agreement existing between the dendrochronological parameters than does Fritts's model which is based on a restricted number of sites (i.e. 7) (Fritts *et al.* 1965, Fritts 1976: Figure 6.18, Page 301). In fact, this Figure 4 demonstrates that the dendrochronological parameters are not perfectly correlated and exactly linked to the climatic gradients existing in Morocco.

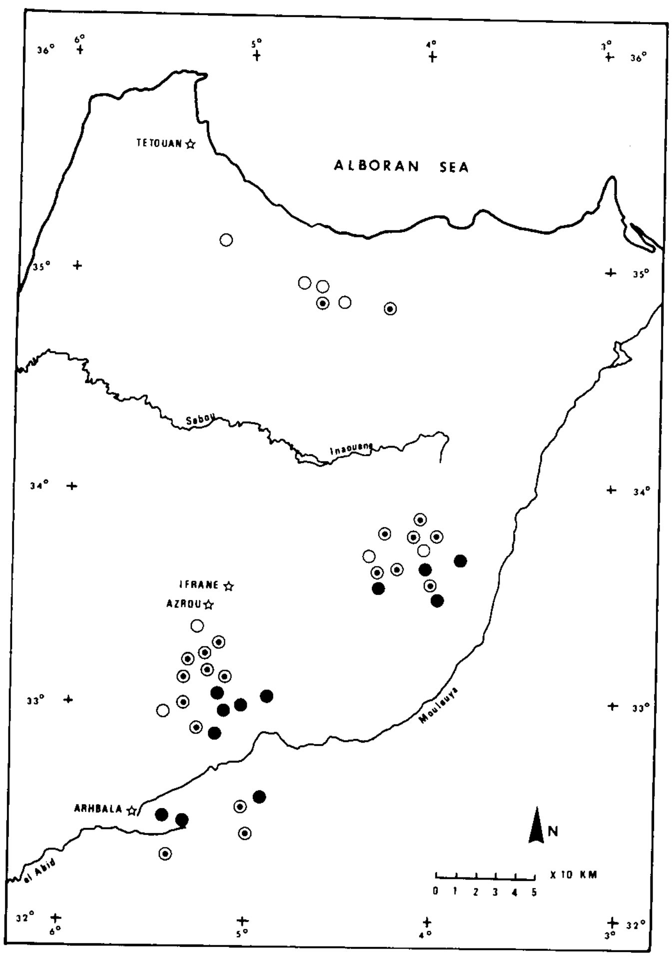

Figure 2. Morocco, *Cedrus atlantica.* The spatial variations of the mean sensitivity (csens): ○ csens <= 0.15 ⊙ 0.16 <= csens <= 0.29 ● 0.30 <= csens

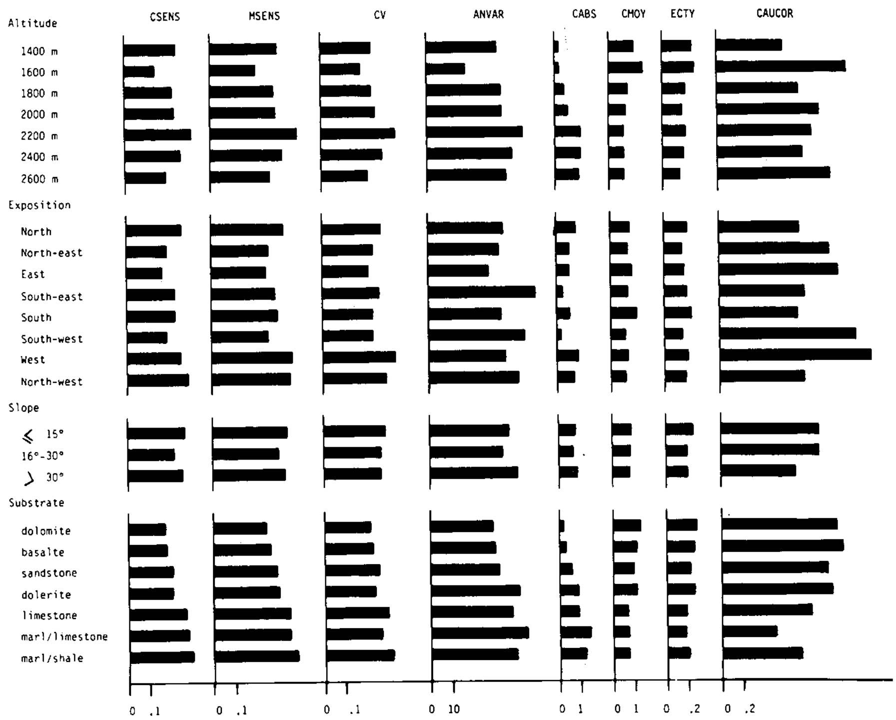

Figure 3. Morocco, *Cedrus atlantica.* Variations of the dendrochronological parameters as a function of the topography and the substratum. csens = chronology mean sensitivity, msens = average of the mean sensitivities of individual cores, cv = coefficient of variation, anvar = percentage of variance attributed to the chronology, cabs = percentage of missing rings, cmoy = mean ring, ecty = standard deviation, caucor = first-order autocorrelation coefficient.

THE SUMMARY RESPONSE FUNCTION OF *CEDRUS ATLANTICA*

The summary response function of *Cedrus atlantica* has been determined by synthesizing the response functions computed for each site. The response functions have been computed using multiple linear regression after extracting principal components (Guiot *et al.* 1982).

The predictors are the monthly precipitation and the monthly mean temperature from October (t-1) to September (t) i.e. 24 predictors, selected according to *Cedrus* growth period. The Moroccan meteorological data were observed in Tetouan, Ifrane, Azrou and Arhbala.

According to the results obtained in Till (1984) the response functions have been computed on the mean raw ring-width values. For each site, two response functions have been calculated: the first is based on mean raw width values with persistence and the second one, on the ring-width values without persistence (Guiot *et al.* 1982).

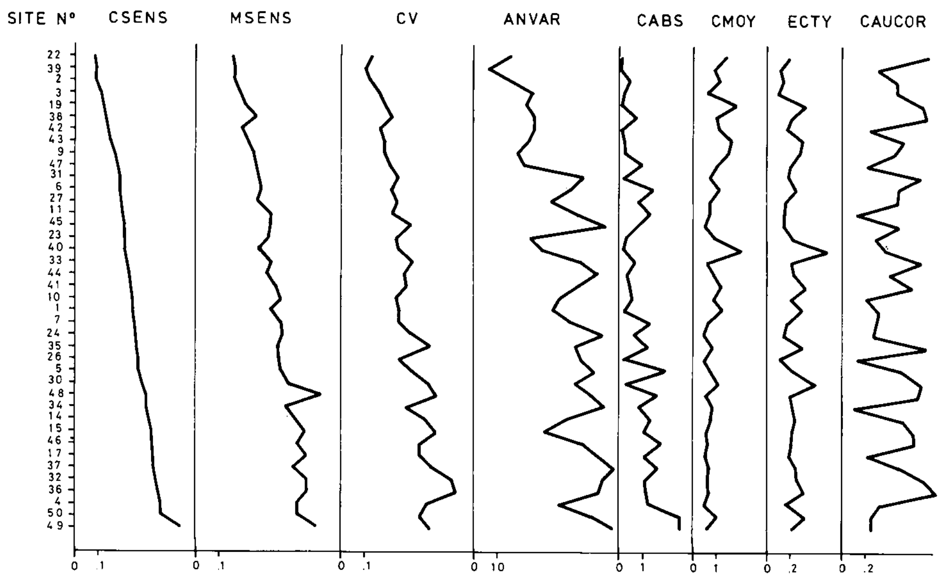

Figure 4. Morocco, *Cedrus atlantica*. Variations of the dendrochronological parameters computed for every site, plotted according to increasing mean sensitivity of the site chronology.

According to the previous authors, persistence is a first-order autocorrelation which play an important role in ring growth and if it is significantly different from 0.00 at a given level (0.10 in this study), persistence must be removed by regression between I(t) and I(t-1). I(t) is thus the ring-width value at time t with persistence; the residual at time t of the regression is the ring width after prewhitening thus the ring-width value without persistence. Response functions have been computed on both ring widths with persistence and without persistence in order to establish the practical value of the prewhitening before computing response function.

Table 2 summarizes the explained variances R^2 of the response functions, the Fisher ratio, F, and its significance level. Only a few R^2 are significantly different from 0.00 at the 0.10 level. On the other hand, the analysis of the 40 response functions shows us many regression coefficients significantly different from 0.00 at the 0.10 level. Climatical signals exist thus in almost every site studied. Moreover the sign of the

Table 2. Morocco, *Cedrus atlantica.* The explained variance of the response functions computed on mean raw ring widths with persistence (R^2) and without persistence (R^2sp). The corresponding Fisher-values are designated by F and Fsp.

Site	R^2	F	R^2sp	Fsp
Tetla de Ketama	0.58	0.91	0.57	0.84
Jbel Tidighin	0.50	0.65	-	-
Tizi Mohkrane	0.43	0.49	0.65	1.20
Agdir Amellal	0.65	1.18	0.75[1]	1.97
Afraskou	0.83[3]	3.20	0.79[2]	2.48
Hayim Tirhist	0.73[1]	1.77	0.69[1]	1.45
Mitkane*	0.78[2]	2.29	0.78[2]	2.29
Ouiouane	0.63	1.09	0.58	0.91
Taffert*	0.91[4]	6.24	0.91[4]	6.24
Bouzemmour*	0.83[3]	3.20	0.83[3]	3.20
Tizi Aït Ali	0.56	0.84	0.73[1]	1.75
Gueb er Rehal	0.69[1]	1.42	0.79[2]	2.42
Col de Zad*	0.62	1.06	0.62	1.06
Aguelmam Azigza	0.38	0.40	0.53	0.72
Jbel Lakrâa	0.76[1]	2.07	0.62	1.07
Tamtroucht*	0.83[3]	3.25	0.83[3]	3.25
Tankararant*	0.70[1]	1.51	0.70[1]	1.51
Tizi Aïni*	0.85[3]	3.67	0.85[3]	3.67
Adrar bou Mellal	0.81[3]	2.69	0.73[1]	1.71
Sidi m'Guid	0.66	1.26	0.74[1]	1.80
Aïn Kahla	0.55	0.80	-	-
Tizi n'Tarzeft	0.64	1.15	0.73[1]	1.74
Jbel Hayan	0.48	0.60	0.65	1.20
Immouzer des Marmoucha*	0.90[4]	5.63	0.90[4]	5.63
Talaharine	0.78[2]	2.36	0.87[4]	4.25
Jbel Tanourdi	0.84[3]	3.37	0.81[3]	2.85
Jaffar	0.70[1]	1.51	0.73[1]	1.77
Ghomara	0.60	0.97	0.41	0.45
Jbel Dahdo*	0.49	0.63	0.49	0.63
Tizi Ifri	0.63	1.09	0.74[1]	1.88
Ich Ramuz	0.53	0.72	0.51	0.66
Jbel Serhla*	0.78[2]	2.35	0.78[2]	2.35
Es Sheb	0.57	0.85	0.76[1]	2.04
Ladmer Izem	0.57	0.87	0.70[1]	1.54
Izdi Ouareg	0.53	0.72	0.65	1.21
Bekrit	0.80[2]	2.54	0.74[1]	1.82
Jbel Irhoud*	0.83[3]	3.16	0.83[3]	3.16
Louta Zad Tafessene	0.54	0.76	0.66	1.26
Bou Izane*	0.86[3]	3.91	0.86[3]	3.91
Amalou'n Moukchab*	0.76[1]	2.03	0.76[1]	2.03

*site for which the first-order autocorrelation coefficient (caucor) is not significantly different from 0.00 at the 0.10 level.

[1] R^2/R^2sp-values significantly different from 0.00 at the 0.30 level.

[2] R^2/R^2sp-values significantly different from 0.00 at the 0.10 level.

[3] R^2/R^2sp-values significantly different from 0.00 at the 0.05 level.

[4] R^2/R^2sp-values significantly different from 0.00 at the 0.01 level.

significant regression coefficients relating to a climatic variable is consistent from one site response function to another. Therefore we conclude that it is rational to determine the summary response function of *Cedrus atlantica* in Morocco.

The summary response function records the weighted occurrences of significant positive and negative regression coefficients from the collection of response functions. The weight given to a regression coefficient is a function of its significance level: the regression coefficients significantly different from 0.00 at the 0.01, 0.05 and 0.10 level respectively receive the weights 3, 2 and 1. The summary response function records for each month the sum of the weights given to the regression coefficients of the corresponding climatic variable. Figures 5 and 6 show the summary response function of *Cedrus* in Morocco. Figure 5 shows the summary response function with persistence, and Figure 6, without persistence. There is practically no difference between the summary response function with persistence and the summary response function without persistence. They show both the same relations existing between ring width and climate. Besides, prewhitening does not really enhance the climatic signal in this case.

The summary response function shows that autumn and winter precipitation play a leading part on *Cedrus* ring width growth. Above-normal precipitation has a positive effect on ring-width. Temperature has a more complex effect. It has a positive effect in January and in August and a negative effect at the beginning (April) and the end (September) of the growth season. There is no significant precipitation in Morocco in summer. The positive effect of October to March precipitation is related to the storage of water in the soil which is later used by the trees during the growth season. It is also related to the regeneration and the growth of some organs (buds, leaf primordia and roots), indirectly involved in diameter growth and which formation occurs for *Cedrus* before cambial activity.

The negative effect of temperature may be related to the water stress (increase of the evapotranspiration reducing growth rate) during the cambial initiation in April and the latest cellular division in September. The positive effect of January temperature stimulates the physiological activities of the trees (photosynthesis and food assimilation, perhaps also production of growth regulators) for the next growth season.

The positive effect of August temperature is surprising because temperature of June, July and September have a negative effect. Three hypothesis may be advanced to explain the positive influence of August temperature:

• high temperature in August might be linked to mist formation which is favourable to *Cedrus* (Peyre 1979);

• high temperature in August are necessary to the growth processes and photosynthesis occurring at the end of the growth season. *Cedrus atlantica* has indeed the possibility to photosynthesize till low drought levels (Aussenac and Valette 1982, Aussenac and Finkelstein 1983);

• high temperature in August would regulate a complex physiological process linked to the growth of cones, this last phenomenon requiring much photosynthate and would be inhibited to the benefit of the radial growth. Nevertheless the biological explanations assumed to demonstrate the validity of the summary response function of *Cedrus* would have to be corroborated by phenological studies extending over several years.

CONCLUSIONS

This large scale dendrochronological study carried out for the first time in the Mediterranean basin on *Cedrus atlantica* growing in Morocco leads to some very interesting conclusions. It demonstrates the influence of the water balance and energy balance on the annual ring growth of *Cedrus atlantica*.

The summary response function confirms that the optimal situation of *Cedrus atlantica* in Morocco is in the subhumid and humid bioclimatic zones of Emberger (Emberger 1971, Daget and David 1982), very cold variant and in the Mediterranean mountain stage. (Quézel 1979, Achhal *et al.* 1980, M'Hirit 1982, Benabid 1982). This conclusion is attested by the positive response of *Cedrus* to autumn and winter precipitation and to January, April and September temperature. The unfavourable effect of April and September temperature may explain the reduction of the competitive ability of *Cedrus* at low altitude; winter cold has the same effect at high altitude. The problems of climatic thresholds (limiting factors) have not been discussed because of lack of meteorological stations established within the cedar forests themselves.

According to response function analysis, climatic signals exist in ring width at almost every site studied. This last result might allow us to compute climatic reconstructions for the Moroccan Rif and Atlas from tree-ring series of *Cedrus atlantica*.

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ACKNOWLEDGEMENTS

We thank the "Institut pour l'Encouragement de la Recherche Scientifique appliquée à l'Industrie et à l'Agriculture" for financial help provided to the author, the Belgian National Fund for Scientific Research and the Belgian Fund for Joint Basic Research which supported the field work. We are indebted to the Moroccan authorities for use of their facilities. Many thanks also to Professor A. V. Munaut for his pertinent comments.

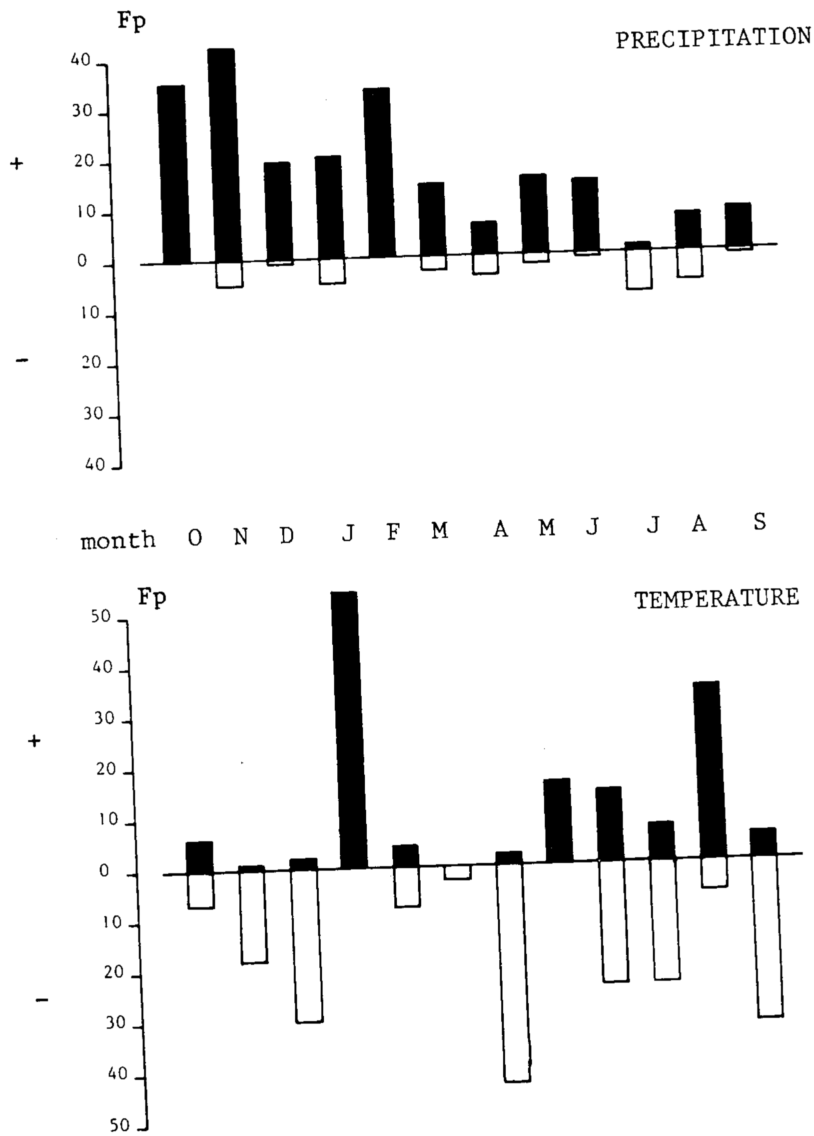

Figure 5. Morocco, *Cedrus atlantica.* The summary response function based on 40 response functions computed on mean raw ring widths *with persistence.* F_p is the weighted frequency of the regression coefficients significantly different from 0.00 at the 0.10 level at least. The climatic variables are the total monthly precipitation and the mean monthly temperature from October (t−1) of the year prior to the season of growth till September (t) of the current year.

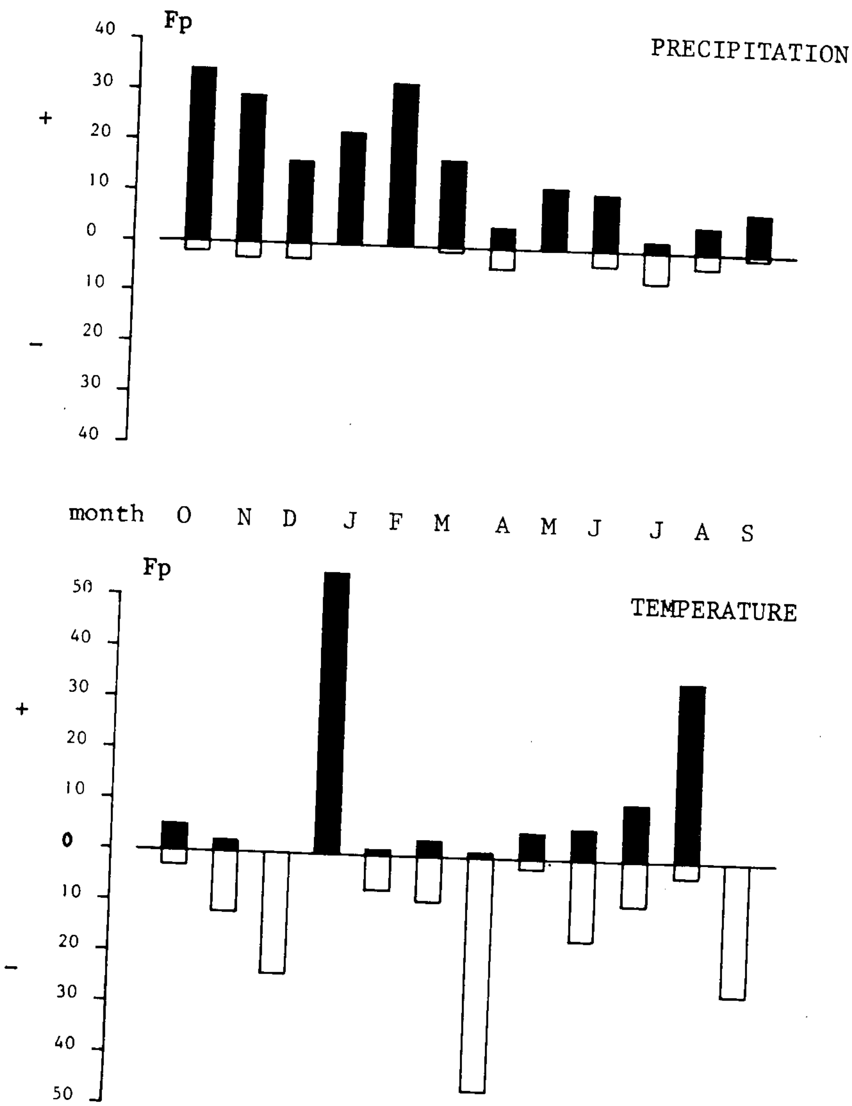

Figure 6. Morocco, *Cedrus atlantica.* The summary response function based on 40 response functions computed on mean raw ring widths *without persistence.* F_p same as in Figure 5.