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VARIABILITY OF THE RADIUS GROWTH AT 25 YEAR OLD PINUS UNCINATA MILLER EX MIRBEL SPECIES IN THE SPANISH NORTH-EAST PYRENEES

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It has been studied the variability of stem radial growth in four radiusorientations at the age of 25 years old trees. The species was Pinus uncinata. The4sampling sites, located in the North East Spanish Pirenees belong to different plant communities. An ANOVA - analysis was performed in order to find out which factors, the radio orientation, plant - community of the site and tree itself are significative or have some kind of influence on the tree radial growth.

Keywords: ANOVA, NESTEL MODELS, MIXED MODELS, PSEUDO-F, SECONDARY GROWTH, RADIO ORIENTATION, COMMUNITY EXPOSURE.

1. INTRODUCTION.

The variability in the wooden species radius growth can be due to different factors such as the slope, the exposure to solar radiation of the site, the soil, the tree habitat and the tree itself,among others. The tree response mechanisms to all of these factors through both geotropic and phototropic processes produce a mechanical stress in branches and stem (Zimmermann et. a./3/).

May be the most notorious example is the reaction wood formation produced in gymnosperms as well as in angiosperms, when -- trees grow on a very strong slope. However , the eccentricity in the radial growth is not so spectacular most of the times. It is a -- consequence of many factors and maybe none of them has a major effect.

Tree physiology mediates the responses - by varying and making the distribution of assimilates and hormones asymemetrical. So we know that tension wood formation (in angiosperms) is induced by a low auxin concentration while compression wood formation is promoted by - high auxin levels (Morey, R.C. /2/).

The stem radial growth irregularity diminishes from the bottom to the dominant apical - meristem. This is logical because it is the lower part of the stem where the root vessels and where reaction wood is formed in a high slope. This is also the part where ilematic stem vessels reinforce the whole tree.

2. OBJECTIVE.

The objective of this work is to study the variability of the radius growth at 25 years of age of the tree species Pinus uncinata Miller ex Mirbel. This species, as the majority of those of the temperature zones, formes growth rings as a consequence of its secondary growth. They are easy to measure with a binocular microscope with a micrometric.

We had two aims in taking the radius until 25 years of age variable: on one hand to study the radius growth variability itself caused by the factors of interest and on the other hand to exclude other factors that affect radial growth rings negatively, that is the production of fruits. This species growth is mainly vegetative during the first 20-25 years. Trees expecting a long future invest in their structure the major part of their production during the first period of their life, which has a different length in years for each species.

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3. ANALYSIS DESIGN. FACTORS OF INTEREST.

The external factors we have appreciated in this analysis as the most important ones in the radial growth of Pinus uncinata have been: the plant community, the radius growth orientation, that is the orientation corresponding to the direction of growth radiis of the stem and the last factor is tree itself.

3.1. THE PLANT COMMUNITY.

The natural habitat of this species is located in the Pyrenees where it forms forests belonging to different plant communities between 1600 and 2000 meters a.s.l. The characteristics of these communities referring to the soil, its exposure and the composition of the accompanying species are specific of each one of them (Table 1). P. uncinata is the dominant species of the communities we have chosen. These are: -- Pulsatillo-Pinetum uncinatae, Arctostaphylo-Pinetum uncinatae and Rhododentro-Pinetum uncinatae. We have included another Pulsatillo-Pinetum uncinatae-D because it has different characteristics from the typical community.

3.2. ORIENTATION FACTOR OF THE SAMPLED RADIUS IN THE TREE.

This factor refers to the direction of the growth radius in the stem of the tree. Four radii with different orientation in the tree were taken North (N), South (S), East (E) and West (W). he purpose of this was to pick up the possible variability produced by factors such as: the soil slope, branch orientation and distribution along the tree, and competition among trees.

3.3. THE TREE AS A FACTOR IN THE ANALYSIS.

As biological systems trees present an intrinsic variability per se . Their sexual reproduction gives them an individual genetic information and thus different from one another. Therefore, although they can grow in similar conditions their responses have need not be the same necessarily. On the other hand, the totality or only some of the trees of an area may suffer damages caused by insects, fire, snow, etc. that - can make the radial growth smaller across the whole section or partially.

TABLE 1

COMMUNITIES

	Pulsatillo	Arctostaphylo	Rhododendro	Pulsatillo-D
SOIL	Basic	Acid	Acid	Basic
EXPOSURE	30 (N-NE)	190 (S)	15 (N)	350 (N)
ALTITUDE	1780 m	1900 m	1800 m	1700 m
SLOPE	28	35	30	35
SITE NAME	MASELLA	COLL DEL PAL	MOIXERO	PEDRAFORCA

Characteristics and sites of the communities where samples have been taken. The Pulsatillo-D community has been included and analysed as one of the levels because it presents a species composition that belongs more to acid soils than to basic ones.

The sites where these communities have been sampled are in table 1, all of these belong to the Cadi mountains in the Pyrenees (Fig. 1)

We have taken the samples almost at the same slope and altitude in order to enable comparison.

3.4. NUMBER OF SAMPLES.

The number of samples was 48. Three trees from each of the four communities and four stem radius growth orientations from each tree. So, it is 3 trees x 4 communities x 4 radio orientations. In this way we had a complete balanced design for each one of the factors (Table 2).

4. ACQUISITION AND PREPARATION OF DATA

So as to measure the 25 year old tree radius we took the samples from the tree stem, at a height of 1 metre from the base with an increment borer.

The cores are mounted and the ring widths are counted from the pit to the 25th tree growth ring. The summatory of these is the length of the tree radius at 25 expressed in cm (Table 2).

Lj is the plant community factor also represented by four levels j=1,2,3,4 that are respectively the four sites' communities.

Ak(j) is the tree factor with k 1,2,3 levels, the 3 trees sampled in each community. Factor Ak(j) is nested in the community as each tree is different from the other.

OLij and OAik(j) represent the interactions radiusorientation-community and radius orientation-tree respectively. We cannot take into account the LAjk interaction because they are nested.

εijk is the aleatory error in the usual hypothesis iid $N(0;\theta^2_\varepsilon)$.

5.1. ANALYSIS OF THE VARIANCE.

The ANOVA models are among the most frequently used in statistical studies of this kind.

TABLE 2

	LA MASSELLA			COLL DE PALL			MOIXERO			PEDRAFORCA		
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
N	7.88	8.61	11.56	4.95	5.30	8.01	5.78	4.95	4.49	6.71	4.68	5.13
S	8.27	8.81	12.66	6.95	6.73	8.11	4.70	5.00	5.62	6.09	4.87	5.35
E	6.88	8.69	11.35	6.93	7.34	8.80	4.98	5.20	5.20	5.40	4.12	4.25
W	8.41	7.77	11.42	6.95	7.60	9.76	5.01	5.11	5.17	6.94	4.59	7.43

Length of the radii at 25 years in cm., for the sample sites of the 4 communities, 12 trees (A1, A2,...,A12) and for the 4 stem radius orientations.

5. STATISTICAL MODEL OF THE DESIGN.

According to the objective and the design followed in the gathering of samples plan, the implicit statistic model is:

$$Yijk = \mu + Oi + Lj + OLi + Ak(j) + OAik(j) + \varepsilon ijk \qquad (1)$$

Where Yijk is the logarithm of the radio at 25 years of age (radio 25).

Oi represents the radio orientation factor with i=1,2,3,4 levels, that are the samples of every tree growth radius orientation (N,S,E and W)

What we have expressed in (1) is the design model of a three way analysis of the variance mixed (2 factors are of random efects and 1 is fixed), factorial in 2 factors (radio orientation-vegetal community and radio orientation-tree) and nested in the factors tree-plant community. Replications are not retrievable due to the construction of the design (Table 3).

TABLE 3

Source of variation	Effect	levels	degrees of freedom	
radiusorientation: Oi	RANDOM	4	Ni-1 = 4-1	= 3
plant community: Lj	FIXED	4	Nj-1 = 4-1	= 3
interaction: OLij	RANDOM		(Ni-1) (Nj-1) = 3×3	= 9
tree: Ak(j)	RANDOM	3	(Nk-1) (Nj = (3-1)×4	= 8
interaction: OAik(j)	RANDOM		(Ni-1) (Nk-1)Nj = 3×2×4	= 24
T O T A L:			N-1 = 48 - 1	= 47

Characteristics of the factors and their interactions.

To analyze the data we took their logarithms because as can be seen in figure 2, variance is not independent from the average: as the level of the observations increases so does the variance.

Furthermore, we point out that the radius orientation factor is treated as random although the samples were taken in a fixed radius orientation, because it is a continuous variable and we took a high enough number of radius orientation samples to cover a large range of variation (A. Prat, verbal communication).

The model hypotheses are:

Oi	iid	$N(0;\theta^2 0)$	$i = 1,2,3,4$
Lj		$\sum Lj = 0$	$j = 1,2,3,4$
OLij	iid	$N(0;\theta^2 OL)$	$\sum_i OLij \neq 0$ $\sum_j OLij = 0$
Ak(j)	iid	$N(0;\theta^2 A)$	$k = 1,2,3$
OAik(j)	iid	$N(0,\theta^2 OA)$	

6 RESULTS.

The calculations corresponding to the Sum of Squares (SS) are given below It is important to be careful with the nested factor.

Sum of squares for the radius orientation factor.

$$Oi-1 = \frac{\sum_{i=1}^{4} (\sum_{j=1}^{4} \sum_{k=1}^{3} Yijk)^2}{4\times 3} - N(\bar{Y})^2 = 0.016278 \quad (A)$$

Sum of squares for the plant community factor.

$$Lj-1 = \frac{\sum_{j=1} (\sum_{i=1} \sum_{k=1} Yijk)^2}{4\times 3} - N(\bar{Y})^2 = 0.512554 \quad (B)$$

Sum of squares for the tree factor.

$$Ak(j) = \sum_{j\ 1} \frac{\sum_{k=1} (\sum_{i=1} Yijk)^2}{4} - \frac{(\sum_{i=1} \sum_{k=1} Yijk)^2}{4\times 3} = 0.147905 \quad (C)$$

Sum of squares for the Olij interaction.

OLij-1 (O-1)(L-1) OLij - Lj - Oi + 1

$$\frac{\sum_{i=1}^{4} \sum_{j=1}^{4} \sum_{k=1}^{3} Yijk)^2}{3} - Lj - Oi + 1 = 0.043005 \quad (D)$$

Total sum of squares (TSS).

$$TSS = \sum_{i=1}^{4} \sum_{j=1}^{4} \sum_{k=1}^{3} Yijk^2 - N(\bar{Y})^2 = 0.754514 \quad (E)$$

Sum of squares for the OAik(j) interaction that is the same as the residual sum of squares (RSS), (see below).

ESS = (E) - (A) - (B) - (C) - (D) = 0.034772

6.1. EXPECTED MEAN SQUARES (EMS).

The expected mean squares turn out to be extremely important as an aid in deciding how to set up an F test for significance - (Hicks /1/). We do EMS using the Yates algorithm (Table 4).

interactions. The F's for the fixed effect factors are calculated with the interaction expression that contains this factor.

In our case all the F's can be calculated without difficulty except for that of the

TABLE 4

Expressions of the expected mean squares.

SOURCE OF VARIATION	4 R i	4 F j	3 R k	1 R m	EMS's
Oi	1	4	3	1	$\sigma^2E + \sigma^2OA + 12\sigma^2O$
Lj	4	0	3	1	$\sigma^2E + \sigma^2OA + 4\sigma^2A + 3\sigma^2OL + 12\emptyset\ L$
OLij	1	0	3	1	$\sigma^2E + \sigma^2OA + 3\sigma^2OL$
Ak(j)	4	1	1	1	$\sigma^2E + \sigma^2OA + 4\sigma^2A$
OAik(J)	1	1	1	1	$\sigma^2E + 3\sigma^2OA$
Eijk	1	1	1	1	σ^2E (not retrievable).

As there are not replications, the degrees of freedom are quite low for the tests indicated in table 4, and since there is no separated estimate of error variance, we do OA 0 to serve as the error variance, and from a biological point of view, OAik has not much interest.

community factor (Lj). This F cannot be obtained directly since no expression contains its EMS. In these circumstances it is of common practice to do a new F called F' or pseudo-F, and new degrees of fredom by a lineal combination taking the right factors and interactions. In this way, we obtain a

TABLE 5

ANOVA table obtained from table 4 with the new expected mean squares expressions.

SOURCE OF VARIATION	D. F.	EMS's	SS's	MS's
Oi	3	$\sigma^2E + 12\sigma^2O$	0.016278	0.0054260
Lj	3	$\sigma^2E+4\sigma^2A+3\sigma^2OL+12\emptyset\ L$	0.512554	0.1708515
OLij	9	$\sigma^2E + 3\sigma^2OL$	0.043005	0.0047783
Ak(j)	8	$\sigma^2E + 4\sigma^2A$	0.147905	0.0184881
Eijk'	24	σ^2E	0.034772	0.0014488
T O T A L	47		0.754514	

To obtain the F's from table 5, we calculate them with the error variance for all the main factors of random effects and random

new mean squares from the interaction OL, the factor A and the error (OA).

MS $MS(OL) + MS(A) - MS(OA)$
MS $\sigma^{2\prime}E + \sigma^2 OL + \sigma^{2\prime}E + 4\sigma^2 A - \sigma^{2\prime}E$
$\sigma^{2\prime}E + 3\sigma^2 OL + 4\sigma^2 A$

Where MS(OL) 0.0047783 with 9 d. of f.
MS(A) 0.0184881 " 8 "
MS(OA) 0.0014488 " 24 "

The F' calculus is :

$$F' = \frac{MS(Lj)}{MS} = \frac{0.1708515}{0.0247152} = 6.91$$

and the new degrees of freedom, v, are:

$$v = \frac{0.0247152}{(1)^2 \times [MS(OL)^2/9] + (1)^2 \times [MS(A)^2/8] + (-1)^2 \times [MS(OA)^2/24]} = $$
$$= 13,5$$

In this way, F's value for Lj factor is 6,91 with 13,5 d. of f. (Table 6).

TABLE 6

F values and signification levels. * significative at 2.5% level ** at 1% level and **** at 5 1 ‰ level. The Lj factor F (.) is a pseudo-F.

SOURCE OF VARIATION	F's	D. of F.	
Oi	3.92	3 ε 24	*
Lj (.)	6.91	3 ε 13	**
		3 ε 14	**
OLij	3.92	9 ε 24	**
Ak(j)	22.21	8 ε 24	****

Starting from these results we will test the Ho,Ho' and Ho'' hypothesis:

$Ho: \sigma^2 On = \sigma^2 Os = \sigma^2 Oe = \sigma^2 Ow = \sigma^2$

Which means that the growth variance in the 4 stem radius orientations is the same; that is to say, the radius orientation factor does not add variability to the radius growth.

Ho' : $L(CESQ) = L(CCP) = L(CMX) = L(CPF) = 0$
$\mu\ L(CESQ) = \mu\ L(CCP) = \mu\ L(CMX) = \mu\ L(CPF) = \mu.$

The width growth or secondary one of P. uncinata species is the same in any of the plant communities.

$Ho'': \sigma^2 A1 = \sigma^2 A2 = \sigma^2 A3 = \sigma^2$

All the trees grow in the same manner and this factor does not add new variability to the radio growth.

Obviously we have to reject all the null hypothesis (Table 6) and to assume that there are significative diferences in the radius 25 growth between stem radius orientations, plant communities and trees.

7. DISCUSSION AND INTERPRETATION OF THE RESULTS.

Statistically, the tree factor is the most significative one. Its interpretation, based on biological facts, can be done in the following way: trees from the same area process a similar external information (climate soil, accompanying species, ...) and they give a different response in their radio growth. A set of exogenous factors , those we know and those we do not notice, have an influence on the level of their physiological processes in a particular way in each tree as a result of the variability in the genetic background. So, while the physiological processes are the ones that mediate the external and internal interactions, the genetic information potentiates and leads these responses.

Every tree is adapted and prepared to give a response to the great amount of changing factors that modify tree space, and habitat, wich is of a fantastic hetereogenity. There is not 1 square metre equal to another neither in time (climate, other species...) nor in space (soil composition, rockness,...).

THE RADIUS ORIENTATION AND THE PLANT community also present significative differences in the trees'secondary growth as well as in their interaction.

In table 1 you can observe the growth of the different communities in the sampling sites: La Masella, represented by CESQ, Coll del Pal by CCP, Moixero, CMX, and Pedraforca that we will call CPF. The community found in CESQ is the one that presents larger differences as we compare them. The differences among the other communities are smaller, -- specially between CMX and CPF. The reasons for CESQ to have a bigger radius growth (25) reside in the particular conditions of this site which are more favorable than the --- others. The topography allows the trees to receive solar radiation almost during the whole day because it is an opener zone. The highest mountain tops to the South, are far away and do not obstruct the direct penetration of solar radiation. It also has the most developed soil of all the sampled communities and is the one that has less slope. The slope has to be interpreted as the soil's capacity for retaining nutrients and water, if it is large the losses are supposedly greater.

The community from which we took samples in site CCP, Arctotaphylo-Pinetum uncinatae, grows in a Southern exposure. For this reason they are exposed to photosyntetically active radiation (PAR) for more hours during the day inciding favorably on production. On the contrary the communities with Northern orientation have generally less direct sun radiation and fewer hours of exposure.

The differences among communities are instead a consequence of other intrinscal factors such as insolation, soil characteristics, topography and the kind of accompanying species. The first 2 of these have,in our opinion, the largest influence. The -- tree configuration also supports this idea. Wnile in CMX and CPF the forest occupy more space vertically, than in CCP and CESQ. The branches and the shape of the trees is more similar between the last two communities which also have a greater radial growth even though they are not so high.

The strategy for radiation is different in CCP and CESQ. The branches grow all along the stem starting almost at the base in most of the trees. They grow horizontally and form a large canopy slightly turned to the SW in CCP. In CMX and CPF the distribution of the branches is in some cases almost apical, specially so in CPF. The lower branches lose their functionality as support elements of assimilatory surface and they finally die.

The wood quality related to the height and diameter of the tree growth, is an important item of forestry wood production studies. The quality increases when the trees are higher. Among the studied communities, the -- best quality is that of the Pedraforca pine woods (CPF).

The radius orientation factor has been commented implicitly when we discussed the plant community since it is closely related to this and to the strategy that the tree has to follow in order to adapt to the given habitat and sun exposure conditions.

It is important to point out that there is no compression wood in none of the studied sites at 1 m height from the base.

The variability among radius orientations within communities is consequence of the incident solar radiation, the competition between tree branches and roots and between the surrounding trees. In CMX the growth is less but more homogeneous. This community has a shorter distance between trees and also a smaller distance variance.

8. CONCLUSIONS.

The radius growth at 25 years of age *Pinus uncinata* species presents significative differences in front of the studied factors: the plant community, the stem radius orientation and the tree itself. We should count on this variability in studies on secondary growth and the stem biomass and when making the data interpretation.

The tree factor appears as the most significative one because genetic information is particular for each one of them and because of the site heterogeneity. For this reason it would be necessary to sample a larger number of trees rather than to pick up more core samples per tree.

The radius orientation and plant community factors have a significative interaction, Therefore their interpretation has to be done at the same time because the location and light exposure of the latter condition a strategy and disposition of the tree's assimilatory surface and consequenthy the radial growth.

The differences between communities are due not only to their exposure but also to the trophic quality of their soils. The pH for CMX is 4,5 and 6 for CPF while in CCP and CESQ it is basic . The first Two soils are more oligotrophic.

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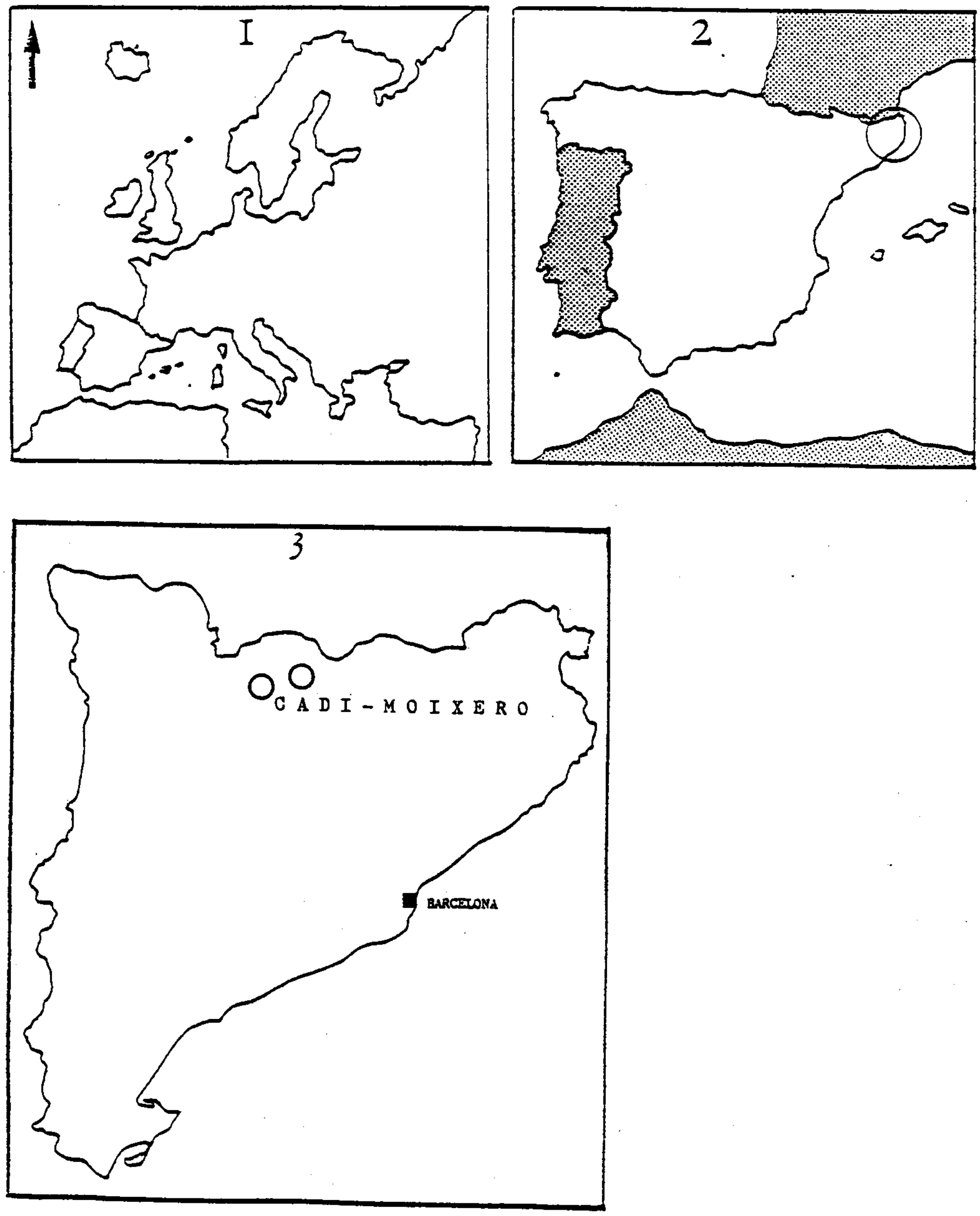

Fig. 1.- Location of the samples sites in the North-East Spanish Pyrenees.

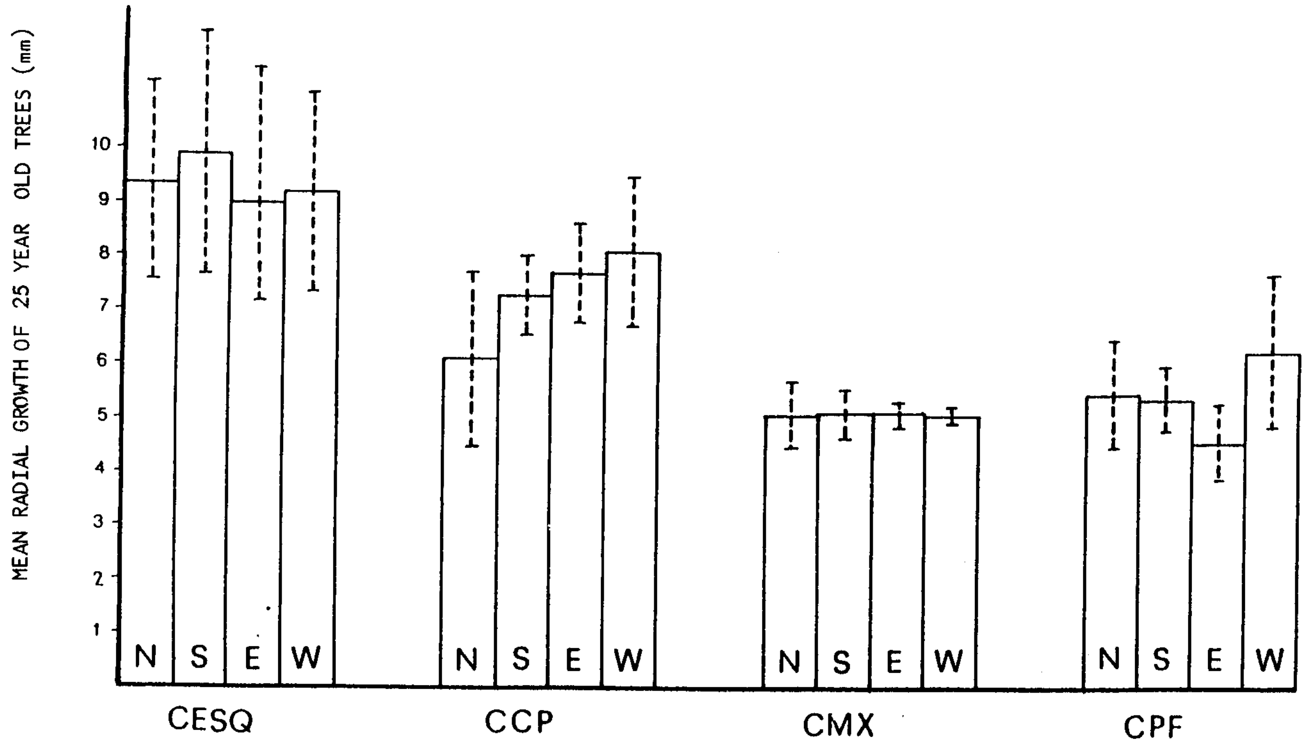

Fig. 2.-Mean radial growth of 25 year old trees. N,S,E and W are the four orientations of the sample in the tree stem, and CESQ, CCP, CMX and CPF are the four sampled sites.