Ann Sci For (1995) 52, 81-88

Original article

An assessment of edge effect on growth and timber external quality of ayous (*Triplochiton scleroxylon* K Schum) under Cameroon rain forest conditions

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(Received 28 August 1993; accepted 19 February 1994)

Summary — An investigation was conducted in order to assess the edge effect on growth characteristics and timber external quality of ayous (*Triplochiton scleroxylon* K, Schum). Average bole height and diameter at breast height (Dbh) were compared for trees growing on the edge and inside the plantation. Only the average Dbh differed significantly between trees of the 2 positions. The external quality of timber was found to decline from bottom to top of the tree, irrespective of the position. This decline was more pronounced in the upper part of the interior trees as compared to the border trees. Finally, a segmented polynomial function comprising a sloping line and a plateau fitted fairly well the decrease in Dbh measured at regular 5 m intervals from the border. The border effect thus appeared to be considerable, though limited to within 10 m of the edge where a 50% decrease in Dbh occurred. This suggests that a guard area of at least 10 m wide should be allowed when sampling an old stand of ayous.

***Triplochyton scleroxylon* / edge effect / bole section / inventory selection / segmented polynomial function**

Résumé — Évaluation de l'effet de bordure sur la croissance et la qualité externe du bois de l'ayous (*Triplochyton scleroxylon* K Schum) dans les conditions de la forêt dense humide camerounaise. *Une étude a été conduite dans la réserve forestière de Makak (Cameroun) dans le but d'évaluer l'effet de bordure sur la croissance et la qualité externe du bois de l'ayous (*Triplochiton scleroxylon *K Schum). À cet effet, on a comparé les hauteurs-fûts et les diamètres (à hauteur de poitrine) moyens des arbres de bordure et de plein champ. Seule la différence entre les diamètres moyens a été significative. La qualité externe du bois décroît du bas vers le haut des arbres, aussi bien en plein champ que sur la bordure. Par ailleurs, cette décroissance est plus accentuée dans la partie supérieure des arbres de plein champ que chez ceux de la bordure. Enfin, on a utilisé une fonction polynomiale* *segmentée comprenant une pente et un plateau pour ajuster la décroissance du diamètre mesuré tous les 5 m à partir de la bordure. Il apparaît ainsi que l'effet de bordure est considérable mais limité aux 10 premiers m où l'on observe une diminution de 50% du diamètre. Ce résultat suggère que, pour l'échantillonnage d'un peuplement d'ayous, on prévoie une marge de sécurité d'au moins 10 m à partir de la bordure.*

Triplochiton scleroxylon / *effet de bordure / section de grume / choix-inventaire / modèle segmenté*

INTRODUCTION

Although the term edge effect is in familiar use amongst agronomists and foresters, it is prone to confusion. Indeed, it refers to any situation where the edge of a plot exhibits a different behaviour from what is observed at the center of the plot. The edge effect may be induced either by a treatment applied to a neighbouring plot or by the presence of uncropped alleyways between the plots. Langton (1990) defined these 2 situations as neighbour effect and border effect respectively. The latter, which is of interest to us, may be attributable to numerous causes. These include (but are not restricted to) differences in exposure to climatic factors (mostly incident light), weed competition and mobility of fertilizer.

It is also commonplace in silviculture for edge trees to exhibit a different pattern of growth and conformation (lack of straightness of timber, poor pruning, *etc*). This explains why the outer rows are usually discarded from sampling.

In spite of these well-reported facts, the literature has not reviewed the subject properly, with possible exceptions related to agroforestry (Vernon, 1968; Langton, 1990). This study was therefore initiated in an attempt to address 2 issues. First, to provide a quantitative evaluation of the border effect on the growth and the external quality of the ayous timber. Second, to determine the distance to which the effect is carried. This aspect is of central importance as it relates to the setting of a guard area necessary for avoiding the border effect.

STUDY SITE AND METHODS

Study site

The study was conducted in the Makak Forest reserve (3°33'N, 11°02E) in the Centre Province of Cameroon. The reserve covers an area of 4 200 ha and forms part of the south Cameroonian plateau with an average altitude of about 400 m. The vegetation is transitional in type between that of Cesalpiniaceae forest and a semi-deciduous forest of Sterculiaceae and Ulmaceae (Letouzey, 1968). The climate exhibits 4 seasons, namely 2 rainy and 2 dry (with one long and one short of each type). The annual rainfall is about 2 205 mm and the mean annual temperature is 24.8°C. The oxisols in the area are characterized by the presence of sandy clay.

The study was carried out in 2 plots of ayous planted in 1937 at 20 x 5 m spacing (Pesme, 1986). The first plot (C6) contains 636 mature ayous trees and is cut through by a road oriented east–west. This road creates a border effect thus motivating our choice for the stand. Since this plot has only 11 border trees, an additional plot (alignment plantation) was selected. The latter consists of 439 ayous trees planted on both sides of a road within the reserve, thus giving a total of 450 border trees.

Species

Ayous (*Triplochiton scleroxylon*, K Schum) belongs to the family Sterculiaceae. It occurs naturally along the West African coast extending from Sierra Leone eastwards to Central Africa in the tropical rainforest. Its ecological exigences include an annual rainfall between 1 000 and 2 500 mm, and temperature between 24 and 27°C. Ayous is a heliophilic species growing in secondary forest at low to medium altitude (up to 900 m). In Cameroon, ayous is found in semi-deciduous forests and the Mount Cameroon zone (Vivien and Faure, 1985). In exceptional cases one can find some patches of ayous in the evergreen forests.

Methods

Two aspects were considered in this study, each requiring a separate sample.

Firstly, an assessment of the edge effect on growth characteristics and external timber quality was undertaken. Fifty border trees were used for this purpose, including all 11 trees from plot C6 and 39 others drawn from the alignment plantation using a one-fourth (one out of every four) systematic sampling scheme (see *eg*, Cochran, 1977). A sample of 85 trees inside the plantation was obtained from plot C6 according to a 2-step scheme whereby 1 out of 3 lines was first selected, from which every fourth tree was in turn selected.

In this paper, the term 'border effect' will refer to the comparison between border and interior trees of plot C6; the term 'site effect' will denote the difference between the border trees of C6 plot and those of the alignment plantation. Finally, where the site effect is not significant, the 'edge effect' will be tested by comparing the pooled sample of border trees with that of the interior.

Secondly, the border effect on diameter was modelled. This study used another sample obtained from plot C6 by drawing every second line and by measuring every tree within the selected lines.

The growth variables measured included diameter at breast height (Dbh) using a measuring tape, and bole height to the crown level (*ie* the insertion point of the first large branch) using a Blume–Leiss hypsometer.

A qualitative assessment of the tree boles was effected using the Lanly and Lepitre (1970) method for tropical tree species. This method proceeds as follows: the bole of a tree is visually divided in 3 sections (lower, median, and upper thirds) each of which is rated separately according to 3 criteria (namely exterior aspect, form and vegetative nature of the bole). The scores for any section are combined in a way that allows its classification in 1 out of 5 categories noted 1 to 5 (with 1 standing for best quality and 5 for worse). These categories will later be referred to as 'inventory selections'.

A segmented (or grafted) polynomial function was used to model the border effect on Dbh. The function that involves a sloping line intersecting with a 'plateau' at an unknown join point Θ is given by:

$$\text{Dbh} = \begin{cases} \alpha_0 + \alpha_1 d + \varepsilon, & d \leq \Theta \\ \alpha_0 + \alpha_1 \Theta + \varepsilon, & d > \Theta \end{cases}$$

where d is the distance (in meters) measured from the border; α_0, α_1, and Θ are parameters to be estimated. The εs are random error terms assumed to be independent; and identically normally distributed with zero mean and common variance σ^2.

Letting T denote an indicator variable such that $T = 0$ if $d < \Theta$ and $T = 1$ if $d > \Theta$, the above function may be conveniently rewritten in the form:

$$\text{Dbh} = \alpha_0 + \alpha_1 [\, d + T(\Theta - d)] + \varepsilon$$

which was fitted to the data using nonlinear regression (Rawlings, 1988).

All statistical analyses were performed with the 6.03 version of the SAS package for personal computers (SAS Institute Inc, 1988).

RESULTS AND DISCUSSION

The border effect on tree growth

Table I gives the summary statistics of the tree characteristics in relation to tree location.

The Shapiro–Wilk test revealed a significant departure of the bole height frequency distribution from normality ($W = 0.95$, $P < 0.001$). This result motivated the use of the Kruskal–Wallis rank sum test for comparing the group means. The site effect on average bole height was significant ($\chi^2 = 5.67$,

Table I. Summary statistics and comparison of average tree measurements at 3 locations. Tests of effect contrasts are based on Kruskal–Wallis Chi-square approximation and Anova *F* tests respectively for height and Dbh.

Variable	*Location (site and position)*			*Test for effects*
	Alignment (n = 39)	*Border (n = 11)*	*Interior (n = 85)*	
Height (m)				
$\bar{\chi} \pm S$	18.5 ± 2.9	20.8 ± 3.9	19.5 ± 4.7	$\bar{\chi}_o^2 = 6.93$ (2 *df*)*
Mode	17.5	20.5	21.5	$\bar{\chi}_S^2 = 5.67$ (1 *df*)*
Range	11.8–25.0	10.08–25.3	5.8–28.8	$\bar{\chi}_b^2 = 0.76$ (1 *df*) ns
CV(%)	15.79	18.65	24.18	
Dhb (cm)				
$\bar{\chi} \pm S$	60.2 ± 10.2	68.6 ± 13.3	45.5 ± 14.4	$F_o = 26.33$***
Mode	61.8	51.6	37.2	$F_s = 3.47$ ns
Range	38.2–83.4	51.6–87.9	11.3–74.5	$F_e = 49.19$***
CV(%)	16.96	19.43	31.56	

Subscripts o, s, e and b stand for overall, site, edge and border effects, respecctively. ns, *, ***: not significant, significant at 5% and 0.1% levels of probability respectively. The computed *F* values have 1 and 132 *df*s in the numerator and denominator respectively.

$P < 0.05$) while the border effect was not ($\chi^2 = 0.766$, $P > 0.05$). This result confirms the fact that bole height is strongly related to site index which is a measure of stand fertility (Husch *et al*, 1982). Moreover, height variability in border trees was smaller (CV = 18.65%) than inside the plantation (CV = 24.18%) probably due to competition for light, which is known to result in vegetative strata (*ie* dominant, codominant, dominated and supressed). Altogether, these findings suggest that any light effect favourable to border trees tends to level off in old stands, thus confirming the results obtained by Pesme (1986).

Like bole height, the Dbh was more variable inside the plantation (CV = 31.56%) than at the edge (CVs are 16.96 and 19.43% respectively for the alignment plantation and the C6 plot). On the contrary, its frequency distribution was normal. Moreover, the Anova *F* tests (each with 1 and 132 *df*s) showed a reversed situation to that of bole height, that is, the average Dbh was not affected by site ($F = 3.47$, $P > 0.05$) whereas, a strong edge effect was noticeable ($F = 49.19$, $P < 0.001$). These results agree with those of Catinot (1965) and reflect the heliophilic behaviour of ayous. Indeed, ayous trees growing at the edge receive more light and tend to grow more rapidly in size than those inside the plantation.

The border effect on timber external quality

Table II gives a 3-way classification of timber count according to location, section order and inventory selection. The latter was grouped into 3 categories (1, 2 and 3 or lower). The log-likelihood ratio test (or *G*-test) for independence (Zar, 1984) was per-

Table II. Three-way classification of the timber count according to location, inventory selection and section order (figures in parameters are column percentages).

Section	Inventory selection	Location (site and position) Alignment (n = 39)	Border (n = 11)	Interior (n = 85)	G-test for effects
Lower					
	1	38 (97.44)	10 (90.91)	76 (89.41)	$G_o = 4.242$ ns
	2	1 (2.56)	1 (9.09)	6 (7.06)	$G_s = 0.791$ ns
	≥3	0 (0.00)	0 (0.00)	3 (3.53)	$G_e = 3.451$ ns
Median					
	1	24 (61.54)	8 (72.73)	38 (44.71)	$G_o = 6.19$ ns
	2	11 (28.21)	2 (18.18)	28 (32.94)	$G_s = 0.535$ ns
	≥3	4 (10.26)	1 (9.09)	19 (22.35)	$G_e = 5.661$ ns
Upper					
	1	2 (5.13)	4 (36.36)	4 (4.71)	$G_o = 12.892$**
	2	10 (25.64)	4 (36.36)	17 (20.00)	$G_s = 8.796$*
	≥3	27 (69.23)	3 (27.27)	64 (75.29)	$G_e = 12.310$*

G_o with 4 *df*, G_s, G_e, G_b with 2 *df* respectively for testing overall, site, edge and border effects. Note that G_s for the lower section is based on a single *df*. ns, *, **: not significant and significant at 5 and 1% levels of probability, respectively.

formed for each section separately. It appears that classification into inventory selections bears no significant relationship to location except for the upper tree section, which tends to be of lower external quality for interior trees than for border trees ($G = 12.310$, $P < 0.05$). A similar result was obtained with site comparison as well ($G = 8.796$, $P < 0.05$). The border effect is most probably due to the greater taper associated with the upper bole section of the interior trees. Furthermore, examination of the cell frequencies in table II reveals a decline in the timber external quality from bottom to top. This trend was confirmed using the pooled data for the lower and median sections ($G = 58.138$ with 2 *df*, and $P < 0.001$). This result was not unexpected. According to Lanly and Lepitre (1970), the bulk of commercial wood is provided by the lower and median sections which constitute respectively 44 and 33% of the timber volume. The upper section, representing the remaining 23%, is usually assigned to local use because of its poor external quality.

Modelling the border effect on Dbh

Figure 1 depicts a decreasing trend of Dbh measured at regular 5 m intervals from border. Indeed, it can be seen in table III that the average Dbh was halved from border to just 10 m inside plantation followed by a slight increase at 15 m from which it stabilizes. This finding was the reason for choosing the segmented model described earlier.

Table IV provides a summary of the nonlinear regression output obtained with the Marquardt option of the PROC NLIN in SAS. The meeting point Θ was estimated to occur

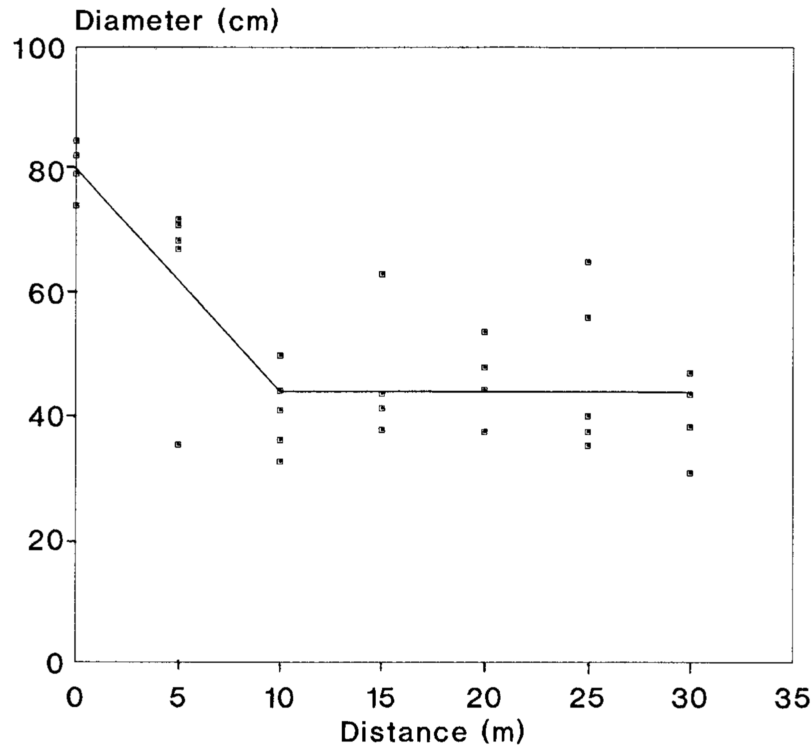

Fig 1. Change in Dbh with distance from border. The fitted model (—) is overlayed on the data points.

Table III. The relationship between Dbh and distance measured from border.

Distance (m)	*Sample size*	*Dbh (cm)*			
		Min	*Max*	$\bar{x}$	*S*
0	4	74.2	84.7	80.1	4.5
5	5	35.2	71.9	62.7	15.5
10	5	32.5	49.7	40.6	6.7
15	4	37.6	62.9	46.2	11.4
20	4	37.2	53.5	45.6	6.8
25	5	35.0	64.9	46.6	13.1
30	4	30.6	46.8	39.7	7.1

at 10 m. The correlation estimates are moderate, except for the coefficient between the slope α_1 and the 'join' point Θ which is 0.926. This value however, does not raise concern for overparameterization. Finally, inspection of the asymptotic 95% confidence intervals indicates that all parameter estimates differ significantly from zero. Thus the fitted function (shown in fig 1) has the following expression

$$\text{Dbh (cm)} = \begin{cases} 80.5 - 3.7d, & d \leq 10.0 \text{ m} \\ 43.5, & d > 10.0 \text{ m} \end{cases}$$

Two comments bear mention here. First, the border effect can be appropriately dealt with by providing a guard area at least 10 m wide.

Table IV. Summary of the nonlinear regression output including point estimates, asymptotic standard errors (ASE), 95% confidence intervals (CI) and correlation matrix.

Parameter	*Estimate*	*ASE*	*95% CI*		*Correlation matrix*		
			Lower	*Upper*	α_0	α_1	Θ
α_0	80.527	4.972	70.342	90.712	1	–0.745	–0.478
α_1	– 3.676	1.334	–6.409	–0.943		1	0.926
Θ	9.999	2.832	4.20	15.80			1

Second, in a separate work Mayaka (1993) compared this model to 3 other segmented polynomial functions for their fit to the present data. He used such criteria as mean deviation, root-mean-square deviation and fit index (analogous to the coefficient of determination). Although none of the functions unequivocally improve on others, the above model could be recommended if only for simplicity besides the fact that it gave the smallest residual mean square while accounting for 65% of the total variation (actually the largest observed fit index).

CONCLUSION

This investigation aimed at appraising the border effect on the growth and timber external quality of ayous. No significant border effect was found with respect to height growth whereas the average Dbh was significantly larger on the border than inside the plantation. A grafted polynomial function was used to model the decrease of Dbh with distance from border inward. The decrease appeared to be considerable but limited to within 10 m of the border.

As for the external quality of timber, it was found to decline from bottom to top, irrespective of the tree position. In addition, the upper part of timber was of significantly lower quality for the interior trees as compared to the border trees.

From these findings, we make the following suggestions. Firstly, a guard area of at least 10 m wide (or equivalently 2 guard rows) is necessary when sampling a stand of mature ayous. This precaution should suffice to prevent the vitiation of the sampling results by the outer rows.

Secondly, when sampling an old stand, border trees could be included insofar as height estimation alone is concerned. However, their inclusion is not appropriate for estimating diameter as it will lead to an upwards bias.

The planting of ayous could be done along both sides of the forest roads in 1 or 2 lines depending on whether 5 m spacing is increase or maintained. This should not only favour the diameter growth but could also improve the aesthetics of such roadsides.

Finally, good care should be taken of the border trees as their quality is similar to that of trees inside the plantation. This would result in additional revenues due to larger bole volume of the outer trees.

ACKNOWLEDGMENTS

We gratefully acknowledge the helpful comments of T Tshibangu, DA Focho and F Tetio-Kagho, who contributed in improving the content of this paper. We also thank T Mienje for handling the manuscript.

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