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Original article

Border effects and size inequality in experimental even-aged stands of poplar clones *(Populus)*

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Summary — Five poplar clones were studied in short rotation intensively cultured (SRIC) plantations in Belgium (Afsnee) and in France (Orsay). Unrooted cuttings were planted with a single spacing of 0.8 x 0.8 m, using 81 or 25 trees per cultivar (density = 15 625 trees/ha). The height of stems was measured, while the size inequality of each stand was examined with the Gini index *(G)* and the coefficient of variation *(CV)*. At both sites the *G* values reflected very high size equality, whereas some border effect was found along the southern side (r_9: row 9) of the Afsnee-stands.

D'Agostino-Pearson K^2 / Gini index / height / Lorenz curve / unplanned multiple comparison method

Résumé — Effet de bordure et inégalité de taille dans 5 clones de peuplier *(Populus)* installés dans des plantations expérimentales équiennes. *Cinq clones de peuplier ont été étudiés en taillis à courtes rotations en Belgique (Afsnee) et en France (Orsay). Au total 81 (Afnee) respectivement 25 (Orsay) boutures sans racines ont été plantées pour chaque clone à un espacement fixe de 0,8 x 0,8 m (densité = 15 625 arbres/ha). La hauteur des tiges a été mesurée. L'inégalité de la taille de chaque clone a été examinée avec l'indice de Gini* (G) *et le coefficient de variation* (CV). *À Afsnee (tableau I) de même qu'à Orsay (tableau II), les valeurs de* G *montrent une très grande égalité de taille, tandis qu'un effet de bordure est démontré le long du côté sud* (r_9 = *rangée 9) des plantations à Afsnée (fig 1).*

D'Agostino-Pearson* K^2 */ courbe de Lorenz / hauteur / indice de Gini / méthode non-planifiée de comparaisons multiples

INTRODUCTION

The development of plants within experimental plots is partially determined by external factors, one of which is the border or edge effect. Various crops have already been studied in this regard, *eg,* soybean (Hartwig *et al,* 1951), cotton (Green, 1956), rice (Gomez and De Datta, 1971), wheat (Konovalov and Loshakova, 1980), Norway spruce (Gaertner, 1983) and poplar (Hansen, 1981; Zavitkovski, 1981; Bisoffi, 1988). Moreover, Cannell and Smith (1980) state that the border effect is always present and point out that it can have a large impact upon the estimation of yields. According to Hansen (1981), "... the necessary border width [is] the distance inward from the plot edge to a point at which there is no further tree height growth gradient". When drip irrigation and fertilization were sufficiently supplied both on the plot and far beyond the unplanted alley, only canopy competition for light can be responsible for the development of a border width and a homogeneous plot center. In our case irrigation water and fertilizers were sufficiently and uniformly supplied but only on the plots themselves.

Plot yield estimations are affected by the development of each individual within a particular stand. This development may be influenced by other factors, *eg,* the availability of limiting resources. This may be the origin of size hierarchies of individuals. The concept of 'size inequality' (Weiner and Solbrig, 1984) can be used for describing these size hierarchies. The increasingly disproportionate use of resources between the taller and the smaller individuals results in a growing one-sided competition (Firbank and Watkinson, 1990) and at the same time in a growing size inequality.

The objectives of this paper are twofold: (1) to characterize a number of poplar cultivars by some statistical parameters (*ie* size inequality); and (2) to assess the border effect in experimental plots as influenced by both the N-S gradient and the position of individual trees.

MATERIALS AND METHODS

Study areas

A short rotation intensively cultured (SRIC) plantation of poplar (*Populus* sp) was grown at the location of Afsnee (51° 02'N, 03° 39' E) in Belgium, in a fenced plot of 10 x 70 m on a loamy sand soil.

Dormant unrooted hardwood cuttings were planted in April 1987, after being submerged in water for 48 h in complete darkness. The criteria for the selection of the cultivars were disease resistance, photoperiodic response, cold resistance and productivity. The following clones were used: Robusta (ROB) as a reference clone; Fritzi Pauley (FRI); Columbia River (COL); Beaupré (BEA); and Raspalje (RAS). Details about the clones (scientific names, places of origin, productivity range, parentage) were given in Ceulemans *et al* (1984). Eighty-one cuttings per clone were set out in a 9 x 9 square planting pattern with a single spacing of 0.8 x 0.8 m. Each clonal block was surrounded by an unplanted alley of 1.5–1.6 m width. Weed control was achieved either by mechanically shallow ploughing or by herbicides (Simazine and Glyphosate). Fluctuations of the groundwater table were controlled with 1 piezometer per clonal block.

At the location of Orsay (48°42'N, 02°12'E, near Paris at about 280 km SSW of Afsnee) in France, another SRIC plantation was established at the same time in blocks of 5 cuttings x 5 rows. Three clones were retained: ROB, BEA and RAS. Weeds were removed by hand. At the end of the first year, the stems were harvested as well as the coppice shoots at the end of the third year (1989).

Measurements

In the period 1987–1989 the stem height at Afsnee was measured every 3 weeks with a double meter rule, a 5 m iron stick or a 7 m aluminium telescopic pole (Téléscomètre TM7-Le Pont Equipments), depending on the developmental phase of the stands. Data on height at Orsay were collected on the longest shoot of each coppice stool. At Afsnee, however, only the stem was involved. Only end-of-growing-season (October–December) measurements are analysed statistically in this paper.

Data processing

The height data for the trees that died (n = 14) during the first year were substituted by the means of the immediate neighbors.

The following statistics were calculated: mean; standard deviation; 95% confidence limits; the coefficient of variation *(CV)*; and the Fisher's coefficients, completed with the K^2-statistic as proposed by D'Agostino *et al* (1990). Skewness was described by $Z((b_1)^{0.5})$ where $(b_1)^{0.5}$ is Fisher's coefficient and $Z((b_1)^{0.5})$ the corresponding approximate normally distributed statistic. Kurtosis was described by $Z(b_2)$ where b_2 is the Fisher's coefficient and $Z(b_2)$ the corresponding approximate normally distributed statistic. Combination of both statistics yields K^2, which allows detection from normality due to either skewness or kurtosis.

Homoskedasticity between rows was tested with Bartlett's procedure (in the case of normal distribution) or the Scheffé-Box test (in the case of non-normal distribution, Sokal and Rohlf, 1981). In the former case, either the F-test or the GH-test (Games and Howell, 1976) could be applied on the row means depending on homogeneity or heterogeneity of the variances. If the F-test was significant, the Tukey test was used. The nonparametric sum of squares simultaneous test procedure (SSSTP, Sokal and Rohlf, 1981) protected the Kruskal–Wallis test in the case of a non-normal distribution and homogeneous variances. With homogeneous variances only extreme skewness should be a problem for the application of parametric one-way ANOVA and unplanned multiple comparison procedures (UMCPs). A precise limit for the concept extreme does not exist, however, so we preferred a very stringent but clear condition. Therefore, if 1 row out of a set of rows proved to be non-normally distributed at the 5% level or lower, the whole set was further analysed with nonparametric tests. However, following Day and Quinn (1989), we avoided "overreliance on the religion of significance".

Testing the means of the central trees and the northern and southern rows as components of the inner and outer border (at Afsnee r_1 = row 1, r_2 = row 2, r_8 = row 8 and r_9 = row 9; at Orsay r_1 = row 1 and r_5 = row 5) was carried out as described above at Afsnee and with the Mann-Whitney test at Orsay (Siegel and Castellan, 1988). Because each central block at Afsnee consisted of 5 trees x 5 rows, comparison of the northern rows r_1 and r_2 with the southern rows r_8 and r_9 was only made considering the 3rd to the 7th individuals of those rows (the 2nd to the 4th individuals at Orsay).

Size inequality was measured by means of the coefficient of variation *(CV)* and the Gini index *(G)* (Sen, 1973; Egghe and Rousseau, 1990). If perfect quality occurs (G = 0), the Lorenz curve is restricted to a diagonal; otherwise, the data curve is convex and G = 1 when size inequality is perfect.

The Gini index is given by:

$$G = 1 + (1/n) - [2/(n^2\mu)](y_1 + 2y_2 + \ldots iy_i + \ldots + ny_n)$$

where n = number of trees, μ = stand mean, y_i (i = 1, 2, ... n – 1, n) = value for the ith measurement of height and $y_1 > \ldots y_i > \ldots > y_n$.

According to Rousseau (1992) the concentration measures CV and G meet the 3 axioms of permutation invariance, scale invariance and the Dalton–Pigou principle of transfers. Mutual comparison of concentration measures was calculated with the Spearman rank correlation.

RESULTS AND DISCUSSION

General statistics

The stands of Afsnee did not differ from those at Orsay as regards plant spacing, but they did in the total number of individuals, 81 *vs* 25.

At the end of each growing season at Afsnee (table I), the group of clones FRI + BEA + RAS belonged to the taller clones on average; ROB was always the shortest. The 95% confidence interval of BEA did not overlap with RAS. The highest CV values occurred in the first year, the lowest in the

Table I. Statistical parameters referring to height of 5 poplar clones at Afsnee.

Parameter	*Robusta*			*Fritzi-Pauley*			*Columbia River*			*Beaupré*			*Raspalje*		
	1987	*1988*	*1989*	*1987*	*1988*	*1989*	*1987*	*1988*	*1989*	*1987*	*1988*	*1989*	*1987*	*1988*	*1989*
Stand (N = *81)*															
Mean	1.36	3.70	5.42	2.04	4.77	7.41	1.52	4.19	6.41	1.97	4.94	7.66	1.98	4.56	7.15
Standard deviation	0.26	0.40	0.65	0.28	0.43	0.78	0.31	0.49	0.90	0.36	0.55	1.17	0.27	0.41	1,11
CV (%)	19.3	10.8	12.0	13.6	9.1	10.5	20.7	11.7	14.0	18.4	11.1	15.3	13.6	8.9	15.5
Gini	0.108	0.057	0.061	0.070	0.048	0.053	0.115	0.062	0.073	0.102	0.055	0.076	0.073	0.050	0.079
$Z(\sqrt{b_1})$		−4.14	−4.75	−4.73	−4.29	−5.06	−2.18	−4.06	−4.30	−2.26	−5.29	−4.99	−2.48		−4.57
P		$< 10^{-4}$	$< 10^{-4}$	$< 10^{-4}$	$< 10^{-4}$	$< 10^{-4}$	0.0296	$< 10^{-4}$	$< 10^{-4}$	0.0240	$< 10^{-4}$	$< 10^{-4}$	0.0131		$< 10^{-4}$
$Z(b_2)$		2.59	3.13	3.48	2.57	3.65			2.35		3.88	2.97			2.34
P		0.0097	0.0017	0.0005	0.0101	0.0003			0.0187		0.0001	0.0030			0.0191
K^2		23.8	32.3	34.5	25.0	38.9		19.6	24.0	7.5	43.0	33.7	6.2		26.3
P		$< 10^{-4}$	$< 10^{-4}$	$< 10^{-4}$	$< 10^{-4}$	$< 10^{-4}$		0.0001	$< 10^{-4}$	0.0230	$< 10^{-4}$	$< 10^{-4}$	0.0458		$< 10^{-4}$
Rows (N = *9)*															
Means: *P* or P	$< 10^{-4}$	0.0002	0.0038	0.0105	$< 10^{-4}$	0.0226	0.0172	$< 10^{-4}$	0.0040						
Center (N = *25)*															
Mean (C)	1.44	3.80	5.53	2.09	4.87	7.58	1.56	4.27	6.56	1.93	4.85	7.34	1.99	4.62	7.04
Standard deviation	0.29	0.36	0.57	0.21	0.32	0.63	0.27	0.44	0.99	0.39	0.59	1.53	0.31	0.39	1.37
Border (N = *10)*															
Mean (I)	1.45	3.74	5.58	2.00	4.58	7.30	1.61	4.28	6.53	2.15	5.01	7.91	2.03	4.43	6.95
Mean (O)	1.23	3.39	4.98	1.94	4.39	6.93	1.39	3.82	5.80	1.97	4.63	7.32	1.94	4.53	7.19
Standard deviation (I)	0.12	0.15	0.24	0.12	0.40	0.35	0.36	0.42	0.85	0.21	0.36	0.82	0.26	0.31	1.17
Standard deviation (O)	0.18	0.44	0.72	0.40	0.62	0.78	0.48	0.75	0.91	0.43	0.98	1.25	0.27	0.47	0.78
Kruwal (C,I,O)					8.22	8.09			7.76						
					C > I,O	C > O			C > O						

N = sample size. Mean and standard deviation in meters. Degrees of freedom for K^2 = 2, for rows/means = 8 and 72 (if *P*) and 8 (if P); for the Kruskal–Wallis test (Border) = 2. C: central block; I: inner border (or 2nd outermost row); O: outer border (outermost row). Empty cell: value not significant. See text for other abbreviations.

second (RAS 8.9% and FRI 9.1%). Similar values were quoted in Benjamin and Hardwick (1986) who found 7.5% for plants grown in phytotron.

The negative skewness values $Z((b_1)^{0.5})$ indicated that there were fewer smaller trees and more taller trees than expected. In our poplar stands these values generally increased with time, certainly at Afsnee. This could mean that energy was supplied more for primary than for secondary growth of the stem. Considering the kurtosis statistic $Z(b_2)$, leptokurtic curves occurred only once in 1987, 3 times in 1988 and 5 times in 1989. With exception of 3 cases (ROB and COL 1987, RAS 1988) the K^2 statistic was always significant and the height distribution at Afsnee was skewed to the left and heavy in the tails.

At Orsay (table II), the clone ROB was always the lowest at the end of each season. Here too the 95% confidence intervals of BEA and RAS did not overlap. Tree height was always normally distributed in ROB, but only during the first year in BEA and RAS. The data could be interpreted in the same way as those at Afsnee in 1988 and 1989.

The differences between the 2 sites could be attributed to: 1) competition for light, because during the second growing season the canopy at Afsnee closed about 1 month earlier than at Orsay; and 2) the high level of the groundwater table at Orsay dam-

Table II. Statistical parameters referring to height of 3 poplar clones at Orsay.

Parameter	*Robusta*			*Beaupré*			*Raspalje*		
	1987	*1988*	*1989*	*1987*	*1988*	*1989*	*1987*	*1988*	*1989*
Stand (N = 25)									
Mean	1.75	2.44	4.02	3.17	4.18	6.38	2.85	3.63	5.49
Standard deviation	0.16	0.39	0.34	0.27	0.40	0.49	0.27	0.47	0.71
CV (%)	9.3	16.0	8.6	8.6	9.7	7.7	9.6	12.8	12.9
Gini	0.049	0.087	0.046	0.047	0.047	0.038	0.052	0.062	0.054
$Z(\sqrt{b_1})$					–3.62	–3.21		–3.46	–4.29
P					0.0003	0.0013		0.0005	$<10^{-4}$
$Z(b_2)$					3.17	3.11		2.61	3.42
P					0.0015	0.0019		0.0092	0.0006
K^2					23.2	20.0		18.7	30.2
P					$< 10^{-4}$	$< 10^{-4}$		0.0001	$<10^{-4}$
Rows (N = 5)									
Medians				0.0184					
Center (N = 9)									
Mean (C)	1.80	2.49	3.97	3.35	4.31	6.48	2.93	3.81	5.74
Standard deviation	0.09	0.33	0.17	0.16	0.25	0.38	0.17	0.31	0.25
Border (N = 6)									
Mean (O)	1.61	2.38	3.85	2.99	3.95	6.04	2.87	3.79	5.74
Standard deviation	0.21	0.17	0.27	0.27	0.61	0.71	0.27	0.17	0.19
Z (C,O)	–2.01			–2.54					
P	0.0447			0.0112					

Degrees of freedom for rows/medians = 4. Z = obtained from a Mann–Whitney test, referring to a standard normal distribution. For abbreviations and symbols see table I.

aged the clones FRI and COL in such a way that neither could be included in this study.

Border effects

The global stand

No differences between the row means in the global stands of BEA and RAS could be detected at Afsnee (table I). The 95% confidence intervals separated the outermost row r_9 from the other rows, but only in ROB 1988 and 1989 and COL 1988. Figure 1 represents these intervals for COL 1988. This could be the result of direct exposition to full sunlight and an increased loss of upper soil water through evaporation. This suggests that a border effect was present from the second year onwards.

There was a significant difference between the row medians in a single case (BEA, 1987) at Orsay (table II).

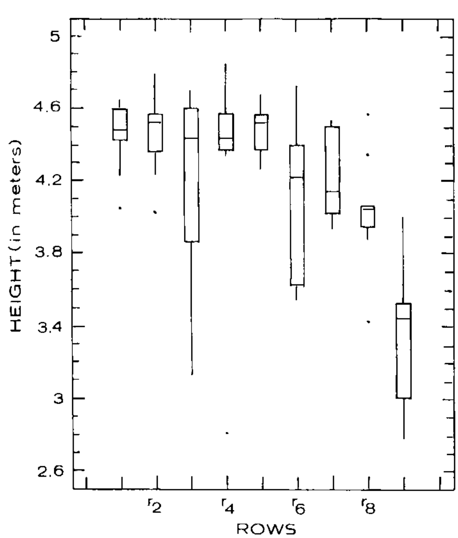

Fig 1. Box and whisker plot of height for the clone Columbia River in 1988 at Afsnee. r_1, r_2, ... r_9 = rows 1 to 9; each row yields information on 100, 75, 50, 25 and 0 percentiles.

In 8 cases the Kruskal–Wallis test (H) was significant at least at the 5% level. Out of these 8 cases the nonparametric SSSTP-test could be applied 7 times (for $N > 8$ and equal sample sizes). This test could detect 5 times a significant difference between row medians. This only happened if the H statistic was significant at either the 1% or the 0.1% level. Consequently, this SSSTP-test was not always appropriate when protected by the Kruskal–Wallis test.

Central and border trees

After 3 years the trees of the central blocks showed the following height sequence at both Afsnee and Orsay: (FRI) > BEA > RAS > (COL) > ROB. The 25 central trees of each clone at Afsnee were a good representative block for the selection of a few model trees (Mau *et al*, 1991), because they were not different from the reduced inner border rows r_2 and r_8. With regard to the reduced outer border rows r_1 and r_9 we got a different picture. The central trees of ROB, BEA and RAS had a similar height to the outermost trees, but the height of FRI (1988–1989) and COL 1989 were higher than the outermost ones. Although Zavitkovski (1981) believed that border trees start to have a growth advantage to inside trees when the canopies close, the Afsnee hybrid poplars already reached a leaf area index (LAI) of 4 (assumed to be the lower limit for a closed canopy) in the month of June of the second year (1988) and the excepted growth advantage was only encountered in RAS.

In contrast with Afsnee, no differences were noted in the 3 Orsay cultivars except in the first year (1987).

The presence of a border effect did not prevent both outermost rows and both second rows developing a flair (Zavitkovski, 1981) in the Afsnee-stands. A one-sided growth of branches combined with an outward bending was observed.

We found the combination of heterogeneous variances and normality 3 times, and the combination with non-normality once. In the combinations with normality the GH-test did not give any indication for differences between the means of central trees, outer border and inner border trees, which was confirmed by the 95% confidence intervals.

Size inequality

At both Afsnee (table I) and Orsay (table II) the Gini values were very low, reflecting a very high size equality.

Weiner and Solbrig (1984) and Weiner and Thomas (1986) strongly argued that positively skewed size distributions and size inequality were 2 different concepts. Skewness only reflects the proportion of large to small individuals and does not reflect the variation between individuals or the dominance of the larger individuals. Some researchers (*eg,* Bendel *et al,* 1989, among others), however, believed that skewness could be used as a measure of intraspecific competition. Highly skewed distributions did not reflect any size hierarchy (Weiner and Solbrig, 1984). This was certainly the case in the Afsnee-stands, where the highly negatively skewed distributions coincided with low *CV* values. Moreover, Weiner and Thomas (1986) reported that 28 size distributions yielded a correlation coefficient of 0.99 between the Gini coefficient and the coefficient of variation. The 15 pairs of the stands at Afsnee produced a very similar correlation coefficient $r_s = 0.98$; the 9 Orsay pairs gave a value of $r_s = 0.87$. Our findings were also similar to those of Bendel *et al* (1989) who found high (Pearson product moment) correlation coefficients between *CV* and *G* ($r = 0.98$ and higher; $150 < N < 189$), at least for the biomass of the *Festuca idahoensis* seedlings. This emphasizes the fact that *CV* and *G* are highly correlated and comparison of the 2 sites is highly admissible. Statistics such as *CV* and the Gini coefficient evaluate the concentration or 'inequal distribution' of biomass more as a degree of size inequality. On average, the frequency distributions at Afsnee deviated from normality with time, indicating that the ratio of taller/smaller trees increases together with the change for dominance and suppression (Weiner, 1985). This was accompanied with the increasing commonness of the leptokurtic curve form.

CONCLUSIONS

At Afsnee all skewness values $Z((b_1)^{0.5})$ were negative and increased with time while the leptokurtic curve was rather common. Cultivar ROB was the shortest and BEA the tallest. *CV* and *G* provided the lowest values in the second year. A border effect was found along the southern side (r_9) of the stands, with ROB, FRI and COL from the second year onwards, and the central block was unaffected by the inner border (r_2 and r_8).

At Orsay ROB was always the shortest clone and BEA the tallest. The size inequality was again very low. No border effect evolved and the central block was generally unaffected by the border rows r_1 and r_5.

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