GROWTH MODELS FOR SPACING TRIALS IN *PINUS PINASTER*

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SUMMARY

1. Equations were fitted to the growth data of 3 spacing trials with nominal spacings varying between 99 and 2966 per ha.
2. Mortality in the three trials differed and was curvilinearly related to SPH.
3. The S%-index decreased curvilinearly with age but in the densest plots remained constant from a certain age onwards.
4. The Chapman-Richards model was fitted to the growth data of each sample plot, for diameter, height and basal area separately.
5. The value of the parameter m in the above model is zero for diameter and height growth, but related to nominal stems per hectare for basal area.
6. For all three growth parameters (diameter, height and basal area), the estimates for the parameters A and k in the Chapman-Richards equation were regressed on nominal stand density, but constraints were introduced to obtain estimates for b.

7. The growth curves for total volume were derived from the growth curves for basal area and height after fitting equations with volume as dependent, basal area and height as independent variables. The estimated MAI's derived from the volume growth curves indicate the extent of the effect of initial spacing on MAI and on its age of culmination.

INTRODUCTION

Between 1937 and 1939 three spacing trials were established in *Pinus pinaster*, to study the relationship between initial spacing and growth parameters. Trial 1 was established in the winterrainfall region of the Western Cape Province in South Africa, trials 2 and 3 in the all-the-year-round rainfall region in the coastal region of the Southern Cape. Each trial consisted of a series of 8 unthinned plots, which however, were all established at the same initial density, corresponding to 2966, 2842 and 2941 stems per ha in trials 1, 2 and 3 respectively. In each trial, plot 1 was left unthinned, the other 7 plots were progressively thinned in advance of competition. The final nominal densities and ages at which they were obtained are given in table 1.

TABLE 1: NOMINAL DENSITIES AND AGES AT WHICH THEY ARE OBTAINED

	Trial 1		Trial 2		Trial 3	
Plot	$SPH_{nom.}$	Age	$SPH_{nom.}$	Age	$SPH_{nom.}$	Age
2	1 483	3,0	1 483	3,1	1 483	2,9
3	989	4,1	952	3,1	989	3,2
4	741	4,9	741	4,8	741	4,1
5	494	6,3	494	5,4	494	4,7
6	371	8,1	371	6,5	371	5,7
7	247	9,6	247	8,6	247	6,8
8	99	13,9	127	9,6	124	9,1

In addition to the basic series of 8 plots each trial contains 8 to 10 plots thinned after the commencement of competition. All sample plots were measured up to 35 years in trial 1, 24 years in trial 2, and 44 years in trial 3.

S%-INDEX AND MORTALITY

Hart-Becking's S%-index, defined as

$$S\% = 10^4 . N^{-\frac{1}{2}} . H_t^{-1}$$

where

N = stems per hectare

H_t = top height

was calculated at those ages of enumeration when a reduction to a lower SPH took place, immediately prior to the onset of competition and regressed on age. The S%-index decreased linearly from 61% at 3 years to 55% at 10 years. The S%-index values, at 34 years in trial 1 and 44 years in trial 3, representing regression estimates with nominal SPH as independent variable were:

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Trial 1	10,3	13,8	16,5	18,8	22,7	26,0	31,3	44,2
Trial 2	8,2	9,6	10,9	12,1	14,2	16,2	29,2	32,1

Obviously the designed densities in the experiments have not ensured free growth in the widest spacing. The relationship between S%-index and age in plots 1 of trials 1 and 3 is shown in figure 1.

In trial 1, the S%-index decreases curvilinearly from 43,8% at 4 years to 10,4% at 34 years. In trial 3, it decreases from 37,0% at 4 years to 8,9% at 44 years. The latter index-values can be regarded as the "natural" S%-index below which s stand, due to mortality does not drop. Mortality, expressed in % of nominal SPH decreases curviliearly with decreasing stems per ha, in trial 3 from 62,1% in plot 1 to 5,4% for plot 8. The latter percentages represent regression estimates, using SPH as predictor-variable.

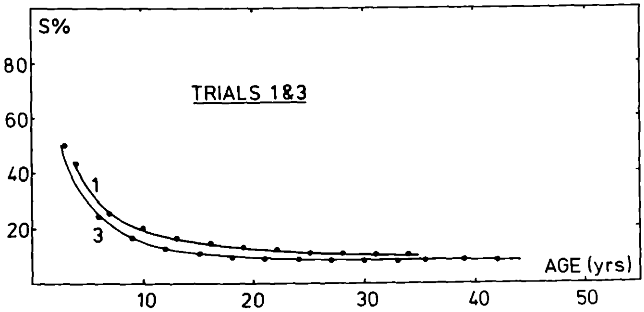

Fig.1
Relationship between age and S%-index

HEIGHT GROWTH

The Chapman-Richards growth model:

$$Y = A(1-b \exp(-kt))^{1/(1-m)}$$

was fitted to the observed heights for each plot, with m being equal to zero. In trial 2 the parameter A, representing asymptotic height, decreases curvilinearly with increasing SPH, but in trials 1 and 3 it was not related to SPH. In equation 1 however, the parameter k was related to SPH.

BASAL AREA GROWTH

The Chapman-Richards growth equation with different values of for m was fitted to the growth data of each sample plot. Those m-values were selected giving the best fit for a given case, i.e. the smallest sum of residual sum of squares. The growth equation was written as:

$$Y^* = \alpha + \beta \gamma^X$$

where

$$\alpha = A^{1-m}, \quad \beta \quad bA^{1-m}, \quad \gamma = \exp.(-k)$$

TABLE 2: FINAL ESTIMATES FOR m, A, b AND k (BASAL AREA)

Trial 1

Plot	m	A	b	k
1	0	86,785	1,1846	0,05939
2	0,05	75,046	1,1723	0,05570
3	0,10	68,043	1,1641	0,05356
4	0,15	63,002	1,1581	0,05206
5	0,15	55,882	1,1535	0,05000
6	0,15	50,851	1,1504	0,04859
7	0,20	43,749	1,1444	0,0467
8	0,35	28,563	1,1236	0,04327

Trial 2

Plot	m	A	b	k
1	0	60,94	1,17065	0,0638
2	0,05	60,94	1,11964	0,0462
3	0,10	60,94	1,09295	0,0371
4	0,15	60,94	1,0780	0,0327
5	0,15	60,94	1,0672	0,0268
6	0,15	60,94	1,0615	0,0236
7	0,20	60,94	1,0527	0,0202
8	0,35	60,94	1,0377	0,0108

Trial 3

Plot	m	A	b	k
1	0,05	94,41	1,2277	0,07877
2	0,15	94,47	1,1798	0,06563
3	0,20	92,20	1,1549	0,05840
4	0,20	89,37	1,1433	0,05368
5	0,25	83,61	1,1227	0,04768
6	0,30	78,30	1,1074	0,04388
7	0,35	69,13	1,0897	0,03910
8	0,40	50,36	1,0653	0,03268

It is of interest to note the different trends for the parameter A, a steep curvilinear decrease with decreasing SPH in trial 1, a less pronounced decrease in trial 3 and no influence of SPH on A in trial 2, although it should be emphasized that a mean square for lack of fit rather than for error is used to test the significance of regression coefficients.

Figure 2 gives the set of growth curves for trial 3.

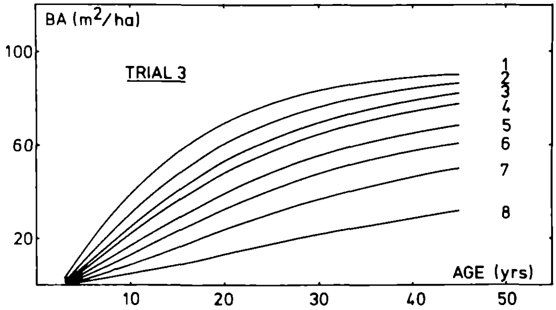

Fig.2
Set of basal area growth curves for trial 3

DIAMETER GROWTH

The Chapman-Richards equation with m=0 was fitted to the single growth series. The parameters α and γ were regressed on SPH after which regression equations with age at the time of the first reduction in stem number as independent and corresponding DBH as dependent vriable were fitted for each trial separately. The growth curves were forced through the corresponding points in these curves. The final estimates for A, b and k are given in table 3.

VOLUME GROWTH

An independent assessment of the volume growth curves, i.e. independently of those for basal area, was considered undesirable because of the resultant disparities between the resultant growth curves for basal area and volume respectively. For this reason the plot measurements at different ages, but for a given sample plot were used to fit the following equation:

$$Y \; 0 \; b_1 + b_1X_1 + b_2X_2 + b_3\;X_3$$

where

X_1 mean height; X_2 basal area per ha;

$X_3 = X_1.X_2$; Y = volume per ha.

In order to obtain the estimated volume at age i for the i-th plot of the k-th trial, the relevant regression equations with basal area, height and basalarea x height as independent variables to obtain the estimated volume at the age of i years. The resultant growth curves and MAI-estimates indicates the extent of the influence of initial spacing on MAI and its age of culmination. The relevant estimates are presented in Table 4.

TABLE 3: FINAL ESTIMATES FOR A, b AND k (DIAMETER GROWTH)

	Trial 1			Trial 2		
PLOT	A	b	k	A	b	k
1	19,05	1,1607	0,09716	16,28	1,0357	0,11213
2	23,92	1,2069	0,09995	19,79	1,0627	0,10011
3	27,20	1,2146	0,09917	22,80	2,0525	0,09181
4	29,76	1,2252	0,09751	24,85	1,0564	0,08690
5	33,75	1,2403	0,09367	28,85	1,0668	0,07865
6	36,89	1,2335	0,08989	32,32	1,0689	0,07233
7	41,88	1,2358	0,08304	38,46	1,0888	0,06290
8	56,22	1,1971	0,06146	52,90	1,0851	0,04560

Trial 3

PLOT	A	b	k
1	20,51	1,1507	0,12009
2	26,23	1,1615	0,10638
3	30,90	1,1586	0,09697
4	34,89	1,1531	0,08987
5	41,64	1,1497	0,07935
6	47,33	1,1430	0,07155
7	46,94	1,1257	0,05996
8	76,94	1,0469	0,03901

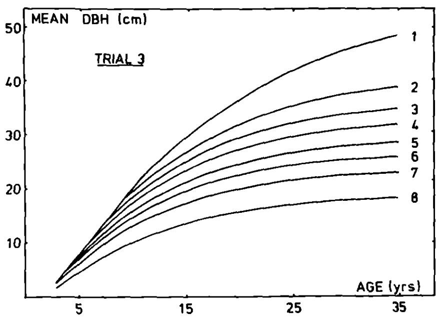

Fig.3

Set of diameter growth curves for trial 3

TABLE 4: MAI AND AGE OF CULMINATION

Trial 1			Trial 2			Trial 3		
SPH	Highest MAI (m^3/ann.)	Age of highest MAI	SPH	Highest MAI (m^3/ann.)	Age of highest MAI	SPH	Highest MAI (m^3/ann.)	Age of highest MAI
2966	14,67	30	2941	11,0	24	2842	30,3	25
1483	10,56	30	1483	8,7	25	1483	24,4	31
989	8,45	30	952	7,8	25	989	21,3	33
741	7,23	31	741	6,7	?	741	18,4	35
494	5,74	31	494	5,5	?	494	14,7	33
371	4,81	30	371	4,9	?	371	11,5	36
247	3,80	32	247	3,9	?	247	9,1	42
99	1,99	34	127	2,4	?	124	4,8	43