PRODUCTIVITY OF FIRST AND SECOND CROPS OF *PINUS RADIATA* ON THE MOUTERE GRAVEL SOILS OF NELSON

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SYNOPSIS

Mensurational investigations into the magnitude, persistence and extent of a possible decline in productivity of radiata pine in its second rotation on Moutere gravels in Nelson were carried out using detailed stem analyses on individual trees from both first and second crops. In some few areas, there have been marked drops in height, basal area and volume growth of the second crop, but in most others the drops are small and on still others none is apparent. Sometimes the apparent drops in productivity are permanent, but mostly they are transitory and confined to the first 5 to 8 years in the life of the second crop.

INTRODUCTION

For many years concern has been expressed about possible impoverishment of soils when successive crops of pure conifers are grown on them. Recently, marked drops in productivity of *Pinus radiata* D. Don. have been reported in South Australia by, for example, Thomas (1961), Keeves (1966) and Bednall (1968). Thus, foresters in New Zealand should at least entertain the possibility of a decline in productivity of exotic crops such as radiata pine in this country, so that remedial measures, if any are required, can be taken soon enough not to interfere with planned, sustained outputs of products. To make decisions concerning such possibilities, the forest manager needs suitable quantitative information.

Evidence is being accumulated in various parts of New Zealand (*e.g.*, Will, 1968; Jackson and Will, 1968) about physical and mineral requirements in the soil for growth of radiata pine. In Waimea County, Nelson, symptoms of severe deficiencies have been observed, but have not been as easily rectified (Appleton and Slow, 1966) as in, say, North Auckland forests, where a dramatic response to application of superphosphate has been reported (*e.g.*, Conway, 1962). Responses in Nelson have been achieved with nitrogen, with or without phosphate, but trace elements such as boron are also often critical, and are particularly deficient on Rosedale soils (Appleton and Slow, 1966).

Chittenden *et al.* (1966) have remarked on various deficiencies for agriculture, horticulture and forestry in all the soil types in Waimea county on which substantial areas of plantations of exotic species, principally radiata pine, are found.

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They found that most of the crops are growing on four main soils — Mapua, Rosedale, Stanley and Spooner. These types, in this order, are found from north to south, with a decrease in mean annual temperature and increases in altitude, rainfall, soil particle size and chemical soil fertility.

Most of the soils in the privately-owned plantations are either of Mapua or Rosedale types, but Golden Downs State Forest is mainly on Spooner hill soils. There is as yet, however, little radiata pine in its second rotation at Golden Downs sufficiently old to allow volumetric comparisons with the growth of the first crop. Thus, this study was confined to comparison of growth on Mapua and Rosedale soils in plantations belonging to private companies.

Stone and Will (1965) have outlined the salient features of tree growth on these soils. Growth of the first crop was generally good, with a mean annual increment of total stem volume inside bark of 24.5 m^3/ha, but on this rolling topography there are considerable variations over very short distances. Much of the land was formerly under orchard, during which period considerable erosion of the topsoil occurred on ridges and upper slopes. Growth of first crops was probably poor on these particular sites as indicated by Verey and Biggs (1952).

Second crops have been naturally regenerated without burning of slash. Numbers of seedlings are often very high except on some ridges and upper slopes, and on areas covered with gorse. For example, Stone and Will (1965) report counts of 60 000 seedlings per hectare taller than 0.23 m in one area of regeneration two years old. Appleton and Slow (1966) state that 50 to 60 000 seedlings per hectare are not uncommon; sample plot number 6, reported upon in this study, contained the equivalent of 12 000 living stems per hectare at 16 years of age. Thus, comparison of growth in basal area and volume between rotations is seriously complicated by the difference in initial stocking.

There are differences not only with respect to initial density and method of establishment, but also perhaps important changes in physical condition of the soil, amount of competing weeds, trace element deficiencies, genetic characteristics, and so on. The possibility of a dysgenic effect is not without foundation. Crops growing on Mapua and Rosedale soils have often been clearfelled at an early age. Natural regeneration could well favour the early and heavy seed-bearing strains with consequent adverse effects on stem volume production. Fielding (1960), for example, has estimated that more than an average of 16% of the total metabolite used in forming stem wood is needed for cone production over a rotation of 40 years of radiata pine in Australia. Thus, comparison between stem volume production from planted and naturally regenerated crops must be viewed with suspicion on this count alone.

In this connection it is interesting to note experience with naturally regenerated crops in South Australia. Keeves (1966) quotes figures from three sample plots in Mount Burr Forest

Reserve for two rotations. In sample plot 14, the first crop was clearfelled at age 41 years, the second crop was naturally regenerated without burning, and measured at age 15½ years. Measurements showed that height and basal area trends were in exactly the same productivity class, according to yield tables, in each rotation. On the other hand, in sample plot 168N, the first crop was felled at age 21 years, the second crop was naturally regenerated with burning and measured periodically from age 14½ to 21 years. Productivity appeared to have dropped by 1½ yield classes. Exactly the same result was experienced in sample plot 169N, when the first crop was felled at age 26 years and no burning took place before the crop was naturally regenerated. Figures from these, the only three remeasured permanent plots on the same site for regenerated second crops, in no way contradict the hypothesis that a dysgenic effect could have resulted from premature felling of the first crops at age 21 and 26 years.

The approach adopted to detect differences in productivity in South Australia is based on accurate and detailed "site quality" mapping. The use of the term "site" and not "crop quality" is somewhat misleading, however. The quality of a site is determined mainly by climatic and edaphic factors (see, *e.g.*, Jackson, 1967). The ability of any one crop to capitalize on these two media refers to that crop alone in the given set of environmental circumstances. Thus, on the main Kaingaroa plateau there is an example of three crops standing side by side, 50-year-old radiata pine, 51-year-old *Pinus ponderosa* var. *scopulorum* and 48-year-old *Pinus ponderosa* from an unknown seed source in California. Stand heights are of the order of 55, 13 and 30 m, respectively. The site is of a uniform quality, but the crop indices of height on age are very different, even for the same species. Jackson (1965) also cites examples in New Zealand where productivity of one species is invariably greater than another on one given site, but productivity may well be reversed on a different soil type.

Crop and not site crop productivity, therefore, is being examined here although the latter may sometimes be implied indirectly. There are four main aspects of crop productivity that are under consideration. Is there a decline in productivity at all? If there is, how large is it? Is it permanent or transitory? And does it occur on all sites equally?

COLLECTION OF DATA

The approach adopted was to try to locate crops of first and second rotations standing side by side, to establish areal sampling units in each at locations which were as closely matched for soil type, topographic position, aspect, etc., as possible, and to study trends in growth of individual trees within these plots in detail. Few crops could be found standing side by side in different rotations. Thus, comparisons have had to be made from sampling units a little distant one from another, but which appeared to possess the same soil type, topographic position, aspect, etc. A brief description of the plots is given in Table 1.

TABLE 1: SUMMARY OF PLOT PARAMETERS IN 1965

Locality	Group	Plot No.	Soil Type	Depth of Soil to Indurated Horizon (cm)	Topographic Position	Rotation	Age (yr)	No. of Stems	Whole Plot G_{ob} (m^2)	Whole Plot V_{ib} (m^3)	Crop Trees only h (m)	Crop Trees only d (mm)	Crop Trees only G_{ob} (m^2)	Crop Trees only V_{ib} (m^3)
Tasman	1	1	Mapua hill soils	20	Lower slope	2	12	83	1.285	11.517	17.8	199	0.375	2.415
		2	" " "	32	" "	2	16	42	1.517	12.949	21.6	258	0.634	4.996
		3	" " "	42	" "	2	21	31	1.899	22.119	30.3	342	1.111	12.035
		4	" " "	>200	" "	1	36	19	2.534	39.304	41.8	452	1.970	27.484
Tasman	2	5	" " "	15	Upper slope	2	12	62	0.470	2.038	10.4	117	0.131	0.563
		6	" " "	19	" "	2	16	119	1.573	11.199	20.4	206	0.404	3.128
		7	" " "	14	Mid-slope	2	16	43	1.024	7.864	19.9	227	0.497	3.553
		8	" " "	25	Just off secondary ridge	2	21	54	1.198	10.134	22.7	233	0.524	4.074
		9	" " "	13	Just off secondary ridge	1	36	24	2.644	31.517	34.2	419	1.704	18.988
Kainui	3	10	Rosedale silt loam	18	Just off main ridge	2	11	63	0.783	4.617	13.8	163	0.255	1.400
		11	" " "	15	" " " "	2	11	46	0.635	3.463	12.7	171	0.282	1.430
		12	" " "	14	" " " "	2	11	60	0.482	2.128	10.8	129	0.158	0.737
		13	" " "	35	" " " "	2	12	96	0.980	6.191	14.7	160	0.247	1.435
		14	" " "	15	" " " "	2	12	84	1.102	6.649	14.9	181	0.312	1.750
		15	" " "	41	" " " "	2	16	73	1.570	12.542	20.4	225	0.483	3.592
		16	" " "	16	" " " "	2	16	67	1.760	13.816	20.0	238	0.550	4.008
		17	" " "	36	" " " "	1	19	20	2.397	28.303	30.9	423	1.750	19.195
Mildura	4	18	Mapua sandy loam	—	Mid-slope	2	12	122	1.346	8.563	15.8	184	0.325	2.040
		19	" " "	21	Upper slope off secondary ridge	2	12	85	0.434	1.912	10.6	103	0.101	0.486
		20	" " "	23	Valley bottom	1	21	21	1.729	17.925	27.5	359	1.286	12.813
		21	" " "	20	Mid-slope	1	21	25	2.346	25.975	29.3	374	1.355	14.212
Waiwhero	5	22	Rosedale hill soils	Not taken	" "	2	20	86	1.377	—	—	—	—	—
		23	" " "	"	Upper slope off secondary ridge	2	20	99	1.217	—	—	—	—	—
		24	" " "	"	Mid-slope	1	44	17	2.592	—	—	—	—	—
		25	" " "	"	Upper slope off secondary ridge	1	44	18	2.100	—	—	—	—	—

Plots in Group 1 are a little distant one from another, but within a circle of radius about 2 km. Plots 5, 6 and 9 in Group 2 are standing almost side by side, but both plots 7 and 8 are about 2 km away from the first three. Plots 3 and 8 are within a few metres of each other as are plots 2 and 7 but in each pair the first is lower down the slope and the second is near the top of the slope.

At Kainui (Group 3) the plots are all standing side by side along a main ridge. Plots 15 and 16 together, 13 and 14 together and 12, 11 and 10 together represent sequences of very short distances down slopes. Plot 17, a crop in its first rotation, is somewhat of an anomaly. It was, however, the only crop of the first rotation left on the ridge, but it was planted at 3.7 × 3.7 m, the seed source is unknown but very different from current second crops, and it is situated on an area that was used to hold horses for many years.

At Mildura (Group 4), plots 18 and 19 are about 1 km away from 20 and 21, but there is only a short distance between plots in each of these two pairs.

At Waiwhero (Group 5), all plots are within a few metres of each other. Unfortunately, however, the crop in its first rotation had received thinning treatment, the second crop had not.

Sample plots 1 to 21 inclusive are square plots of 405 m^2, in which total height (h) diameters overbark at breast height (d) and at half height ($d_{0.5h}$) and four bark thicknesses at breast and half heights of all living stems with d greater than 50 mm were measured. Diameters were measured with steel tapes, bark thicknesses with a Swedish bark gauge where the bark was ridged and with a graduated screwdriver where the bark was not ridged. Heights were measured usually by climbing with a tape and graduated pole, but occasionally with a Blume-Leiss clinometer or by levelling from a neighbouring tree already climbed. Diameters and bark thicknesses were measured to the nearest 0.05 in. (= 1.27 mm) and heights to the nearest 0.5 ft (= 0.15 m).

Twelve dominant trees spaced evenly through the plot were classified as crop trees — *i.e.*, if a low thinning were carried out to about 300 stems per hectare, those 12 would most likely be retained in the plot. Each of these 12 trees was climbed and heights at three-yearly intervals down from the base of the leading shoot were measured with a linen tape and graduated pole. At half height and breast height on these 12 trees, increment cores through the pith were taken on four equally spaced radii.

Finally, two of the 12 trees (randomly from opposite halves of the plot) were felled, sectionally measured and subjected to a comprehensive stem analysis. The method of sectional measurement was as follows:

(1) Every annual shoot was identified and the length of each internode within it measured and recorded to the nearest 0.1 ft (= 0.03 m).

(2) Diameter overbark and four bark thicknesses at the bottom mid-internode of every annual shoot were measured and recorded to the nearest 0.05 in. (= 1.27 mm).

TABLE 2: MEAN HEIGHT (h) OF THE 12 CROP TREES PER PLOT AT DIFFERENT AGES

	Plot		Mean Height (m) at age (yr)										
Group	*No.*	*Rotation*	5	8	11	14	17	20	23	26	29	32	35
1	1	2	6.0	10.7	16.2								
	2	2	2.6	8.8	13.8	18.7							
	3	2	3.3	8.7	13.9	19.0	24.4	29.1					
	4	1	4.3	9.8	15.0	20.3	24.9	29.0	32.8	35.8	38.2	40.1	41.8
2	5	2	3.8	7.0	9.7								
	6	2	5.4	10.2	14.0	17.8							
	7	2	4.1	8.7	13.1	17.1							
	8	2	2.9	7.1	11.1	14.2	18.2	21.7					
	9	1	3.1	7.6	12.4	16.5	20.3	24.0	27.4	30.2	32.2	33.4	34.2
3	10	2	3.6	8.7	13.8								
	11	2	3.4	7.6	12.7								
	12	2	2.7	6.7	10.8								
	13	2	4.6	8.0	13.3								
	14	2	4.1	8.5	13.4								
	15	2	2.6	6.6	12.2	17.2							
	16	2	2.1	5.4	11.2	16.7							
	17	1	4.4	10.3	16.0	21.2	25.4	29.5					
4	18	2	3.5	9.2	14.4								
	19	2	2.6	5.9	9.9								
	20	1	1.7	6.1	11.4	16.6	21.3	26.2					
	21	1	3.1	9.0	14.8	20.0	23.8	28.2					

Thin discs were cut at the bottom mid-internode of every third annual shoot, starting with the first shoot down from the apex. The witdhs of each annual ring and the pith were measured across four radii to the nearest 0.02 mm on a travelling microscope. Ring widths in the increment cores were similarly measured, excluding the pith.

Sample plot numbers 22 to 25 inclusive formed a later comparison at the suggestion of Dr H. Holstener-Jorgensen (visiting research fellow in 1967 and 1968). Again the size of sampling unit was 405 m², but in this case only *d* of each tree was recorded and increment cores were taken on the six biggest and six smallest (except for the very biggest and smallest) basal areas in the plots.

RESULTS

(a) *General*

Parameters describing the plots at time of study are given in Table 1. The volume of each tree was obtained from a regional four dimensional volume function (E. R. Lewis, unpubl. data). The least-squares regression is of the form,

$$v = b_o.d^2h + b_1.d^2 + b_2.dh^2 + b_3.h^2 + b_4.dhd_i + b_5dhd_{0.5h}$$

where v = total stem volume inside bark,

d = diameter overbark at breast height,

d_i = diameter inside bark at breast height,

h = total height,

$d_{0.5h}$ = diameter overbark at half total height,

b_i are regression coefficients ($b_o = 0.0007536$
$b_1 = —0.0199826$
$b_2 = —0.0000892$
$b_3 = 0.0004902$
$b_4 = —0.0000176$
$b_5 = 0.0027930$).

Comparison with volumes computed from sectional measurements of the two felled trees per plot indicated that the form class volume function was a more consistent predictor than the two-dimensional volume table for unthinned stands in Nelson (Duff and Burstall, 1955). The difference between the form class function and the measured volume was 4.4% and between the 2-dimensional volume table and the measured volume was 6.2%. Thus, the form class volume function was used to compute the volume of all trees in the study and, hence, of the plots.

(b) *Trends in Height Growth (h)*

Mean growth in height of the 12 dominant crop trees per plot is presented in Table 2 and shown graphically in Fig. 1 for group 3 by way of example.

TABLE 3: MEAN CROP TREE BASAL AREA UNDER BARK (g) AT VARIOUS AGES

Group	Plot No.	Rotation	Mean Basal Area Underbark (m^2) at age (yr)													
			5	*8*	*11*	*14*	*17*	*20*	*23*	*26*	*29*	*32*	*35*	*38*	*41*	*44*
1	1	2	0.0046	0.0119	0.0203											
	2	2	0.0029	0.0113	0.0193	0.0310										
	3	2	0.0007	0.0085	0.0175	0.0325	0.0486	0.0649								
	4	1	0.0035	0.0149	0.0273	0.0382	0.0483	0.0585	0.0688	0.0803	0.0897	0.1006	0.1130			
2	5	2	0.0018	0.0054	0.0089											
	6	2	0.0035	0.0085	0.0136	0.0195										
	7	2	0.0032	0.0103	0.0160	0.0239										
	8	2	0.0007	0.0047	0.0085	0.0146	0.0210	0.0281								
	9	1	0.0043	0.0171	0.0266	0.0336	0.0400	0.0471	0.0554	0.0641	0.0753	0.0806	0.0886			
3	10	2	0.0020	0.0085	0.0177											
	11	2	0.0018	0.0087	0.0189											
	12	2	0.0008	0.0046	0.0106											
	13	2	0.0033	0.0085	0.0141											
	14	2	0.0034	0.0103	0.0165											
	15	2	0.0008	0.0070	0.0149	0.0239										
	16	2	0.0005	0.0062	0.0169	0.0266										
	17	1	0.0047	0.0244	0.0494	0.0701	0.0873	0.1021								
4	18	2	0.0023	0.0105	0.0185											
	19	2	0.0007	0.0033	0.0059											
	20	1	0.0006	0.0082	0.0223	0.0396	0.0556	0.0740								
	21	1	0.0018	0.0164	0.0362	0.0521	0.0641	0.0796								
5*	22	2	0.0002	0.0026	0.0064	0.0109	0.0166	0.0222								
	23	2	0.0008	0.0033	0.0070	0.0111	0.0158	0.0203								
	24	1	0.0013	0.0122	0.0225	0.0338	0.0442	0.0535	0.0634	0.0741	0.0841	0.0961	0.1088	0.1192	0.1306	0.1396
	25	1	0.0011	0.0108	0.0190	0.0286	0.0368	0.0448	0.0519	0.0586	0.0646	0.0719	0.0804	0.0880	0.0962	0.1037

*Mean crop tree based on only 6 trees per plot.

(c) *Trends in Basal Area (g)*

Mean growth in basal area under bark of the 12 dominant crop trees per plot is presented in Table 3 and shown graphically in Fig. 2 for group 2 by way of example. Basal area trends for the mean of the six dominants in each of the plots 22 to 25 are also recorded in Table 3.

Ring widths could be measured on increment cores only from the edge of the pith out. The width of the pith itself was estimated by a least-squares regression on diameter of first

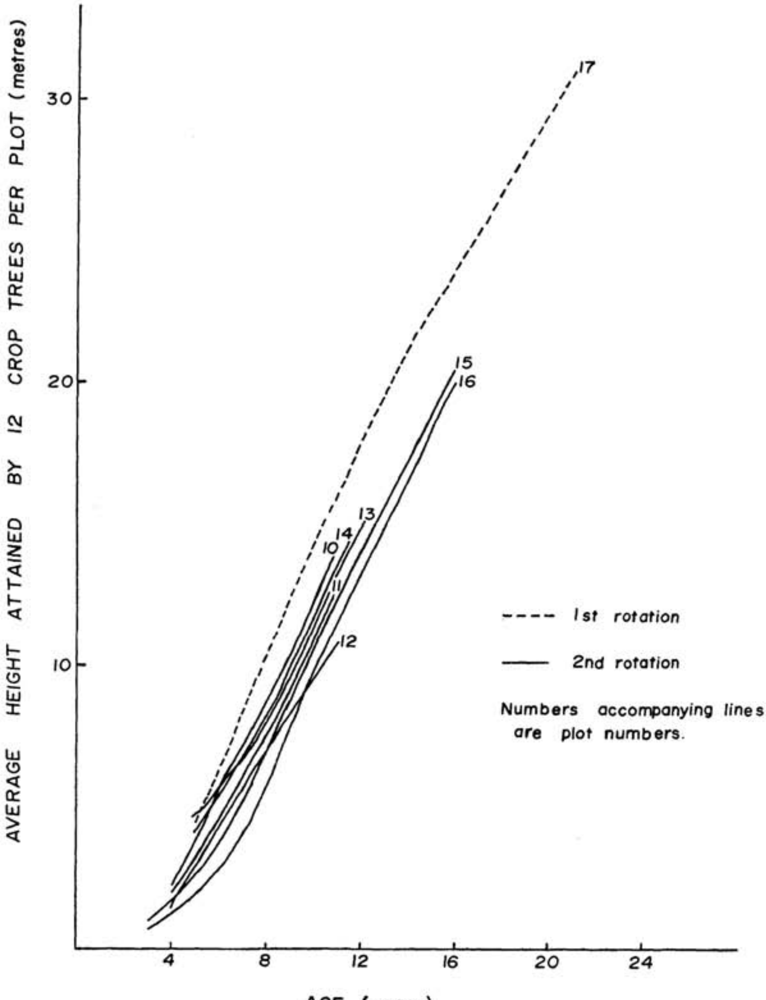

FIG. 1: *Average height attained by crop trees on upper slopes at Kainui (Group 3).*

ring, length of internode and length of previous year's shoot; it is reported elsewhere (Whyte, 1967). This estimated value was then added to the measurements of annual rings. Agreement with mean basal area underbark at age of sampling measured on the one hand by diameter and bark gauge and on the other by increment cores was excellent. For all except plots 4, 9 and 17 (large trees of the first rotation) there is a very slight but consistent over-estimate in basal area for the increment cores compared with diameter measurement by tape and bark gauge.

Straight line regressions of mean basal area on age of crop, $g = b_0 + b_1(T/100)$ were computed for plots 1 to 21 inclusive, individually and in the various groups. Relevant parameters for the regressions for some single plots and groups are presented in Table 4. Analyses of covariance to test for differences

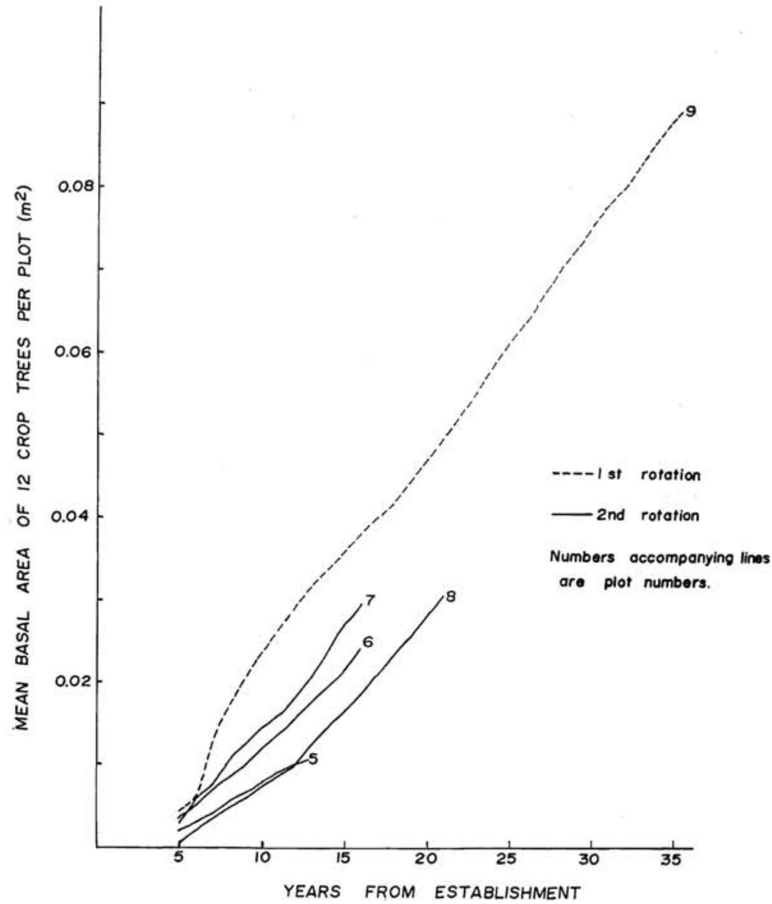

FIG. 2: *Mean basal area attained by crop trees on upper slopes at Tasman (Group 2).*

in these regressions were carried out: there were differences in both residual variances and slopes for all the regressions shown in Table 4.

Basal area at age 30 years was predicted by regression for each single plot and for first and second rotations individually by groups. The latter results are also shown in Table 4.

Current annual increments in basal area for each of the 12 sample trees in plots 22 to 25 were expressed in terms of their basal area at the beginning of the year by various least-squares regression models, but no clear answers were obtained from these analyses.

(d) *Trends in Volume (v)*

Trends in volume of the two sample trees per plot with age were derived and those for upper slopes at Tasman are shown in Fig. 3. Regressions of current annual increment of volume on volume at the beginning of the corresponding year were computed by least-squares using several models. No clear answers emerged from the analysis and so they are not reported further here. Straight line regressions of total volume of the 12 crop trees per plot on the product of their basal area and mean height have been calculated for all first crops together, all second crops together and finally for all 21 plots together. Relevant parameters are given in Table 5.

TABLE 4: STRAIGHT LINE REGRESSION PARAMETERS OF MEAN BASAL AREA OF CROP TREES ON AGE FOR VARIOUS COMBINATIONS OF PLOTS, AND PREDICTED VALUES OF MEAN BASAL AREA AT 30 YEARS OF AGE (g_{30})

Group	*Plots*	b_0	b_1	$S_{(b_1)}(\%)$	$S_g(\%)$	r^2	g_{30}
1	1, 2, 3	—0.0219	0.402615	3.3	2.5	0.962	0.9890
	4	—0.0129	0.356983	0.5	0.3	0.999	0.9420
2	5, 6, 7, 8	—0.0072	0.181191	5.8	3.4	0.865	0.0472
	9	—0.0052	0.267447	1.0	0.5	0.997	0.0750
3	10-16	—0.0130	0.265773	3.3	2.3	0.940	0.0667
	17	—0.0235	0.644506	2.6	1.3	0.990	0.1669
4	13	—0.0113	0.270476	0.6	0.3	0.999	0.0698
	14	—0.0037	0.087500	1.3	0.7	0.999	0.0226
	15, 16	—0.0277	0.519606	3.4	2.2	0.964	0.1282

TABLE 5: PARAMETERS FOR STRAIGHT LINE REGRESSIONS OF VOLUME PER PLOT OF CROP TREES ON BASAL AREA PER PLOT × MEAN HEIGHT OF CROP TREES

	b_0	b_1	$S_{b_1}(\%)$	$S_{(v)}(\%)$	r^2
First crops only	1.8791	0.308775	5.5	1.5	0.991
Second crops only	0.1229	0.352528	0.8	0.7	0.999
Both crops together	0.2884	0.336470	1.1	1.2	0.998

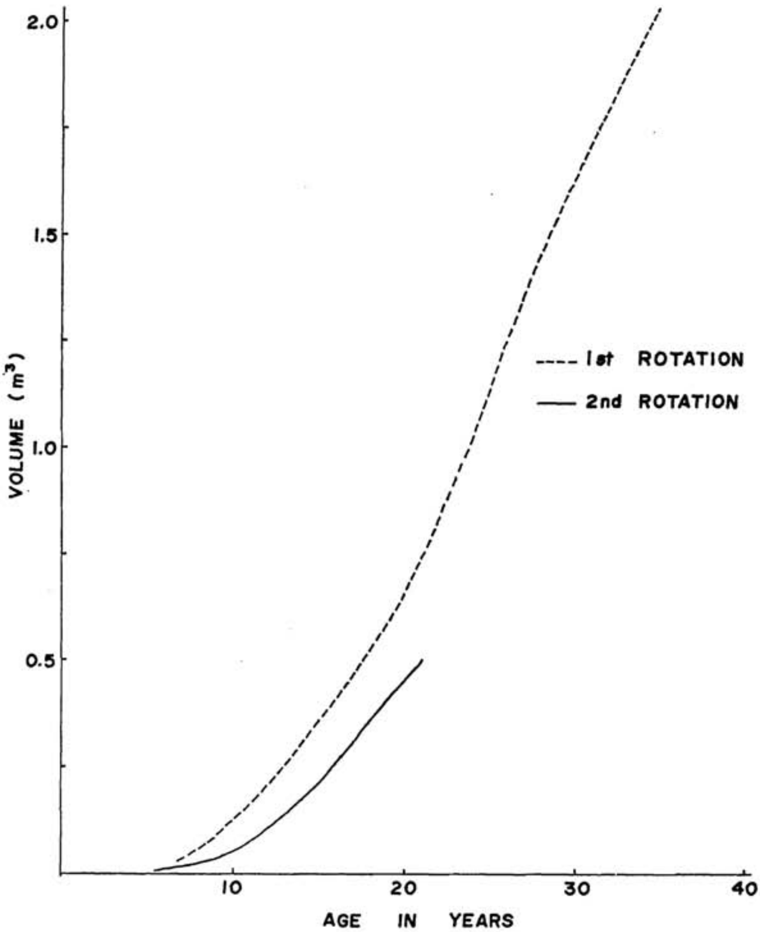

FIG. 3: *Trends in volume of two sample trees per plot on upper slopes at Tasman (Group 2).*

Although the range of data for first and second crops overlap only a little, an analysis of covariance was carried out; it indicated a significant different in both residual variances and slopes at the 0.1% level between regressions for first and second crops (F-values were 57.50 and 13.88, respectively).

DISCUSSION

In the absence of information from permanent plots measured in successive rotations, this study has aimed at providing an indication of relative rates of productivity in one rotation compared with another from temporary plots. It would have been impossible to base results on a study of total dry matter production, since, among other considerations, no records of mortality in first crops were available nor could this factor be reconstructed. Thus, the basis for comparison is confined to the component which has most relevance to commercial forestry, namely trees which would survive, naturally or by design, until felled late in life; *i.e.*, the component that yields sawlog material. This element of the crop, too, is less affected by differences in competition.

Comparison of growth in the two rotations is not at all straightforward. Plots were chosen on sites which appeared to be comparable in terms of parent material, position on the slope, degree of slope, aspect, depth to an indurated horizon, etc. All plots were judged subjectively to be fully stocked, but, apart from the usual criticisms of this assessment, the second crop may have had initial stockings of around 25 000 seedlings per hectare on average, while in the first crop, plots 17 and 18 were established at 3000 per hectare, plots 15 and 16 at 1250 per hectare and plot 19 at 750 per hectare. First crops may well have been conscientiously released, but no such favoured treatment was accorded most of the second crops for this study. In those second crops which did receive thinning to waste, the remaining trees were apparently unable to take advantage of the releasing and further dense regeneration (or regrowth) soon re-asserted itself. Cone production is prolific in radiata pine in Nelson, and so, if natural regeneration did favour heavy and early seeders, stem wood production could be substantially diminished on this count alone. Wherever possible, logging dumps and landings were avoided in locating sampling units, but the nature of logging was such that compaction, and removal of what little topsoil occurs on ridges, could be more extensive than is obvious at first sight. Variability over very short distances and the irregular and scattered nature of the small coupes also made it difficult to lay out quadrats (even as small as 400 m^2) in a uniform part of the second crop. Methods of establishment and re-establishment too are changing all the time, and so the conditions under which the second crops reported here have grown up will probably not be repeated now. Because of all these qualifications that are needed, the results obtained cannot be applied directly. Rather, they represent a source of data, which, in the absence of better information and with suitable modification, could be of assistance to forest managers in indicating possible changes in future yields of their second crops.

The main benefit from this investigation is that the basic data provide good records of growth and development of individual trees and of known components of the crops, which can be used for later comparisons, if needed. It would be particularly advantageous to remeasure each sample plot just prior to felling and to relocate it in the next rotation (see Whyte, 1972).

Growth in height is perhaps little affected by the complications mentioned previously. Table 1 and Fig. 1 show that, with two exceptions, height growth is at least parallel, if not coincident, in both first and second crops from about age 7 years onwards. The two exceptions are plot 5 and plot 19: in the former, boron deficiency was evident in the form of dieback among even the dominants, but this factor did not appear to have debilitated any of the comparable first crop in the same manner, even though it was only a few metres away; in plot 19, vigour in height was apparently affected by the very high total stocking (there were about 20 000 stems/ha with d less than 50 mm alone) and most of the trees possessed merely scant tufts of green crown on the topmost laterals and leading shoot.

In most other plots the difference in height growth is represented by an initial stagnation in height growth, which represents at most 3 years, but usually only one year's loss of growth, which will not change with advancing years. Height growth in plots 1 and 2 is even better than in the corresponding first crop (plot 4) and also in plots 6 and 8 compared with plot 9.

This result shows the importance of not projecting trends in height from measurements at one point of time and from past experience with a previous crop. To appreciate better how height growth will develop, it is necessary to examine past trends in detail and to determine if any initial decline is transitory (as in most second crops reported here) or if it is permanently in a lower class of crop height productivity.

In comparing trends in basal area and volume, it had been anticipated that allowances could be made for differences in stand density at different ages by computing regressions of current annual increment on size at the beginning of the year. The differences in sizes at any one point of time, however, between crop trees of the first and second rotation is sufficiently great to preclude any valid comparisons between regressions.

Only on the lower slopes in Tasman Forest were second crop trees growing in basal area and volume faster than, or as fast as, first crop trees. On upper slopes in Tasman Forest and at Kainui a slightly sigmoid rather than straight line trend is evident, indicating that initial stagnation in basal area in the second crop continues longer (until about eight and not four years) than in the first. While height stagnation lasted a maximum of three years, basal area and volume stagnation continued for a longer period.

This factor affects the interpretation of the predictions of basal area at 30 years by straight line regression. Thus, on upper slopes in Tasman Forest, a graphical projection indicates that the same basal area as in the first crop at age 30 years would be attained at age 37 years compared with an estimate by regression of 45 years of age. Similar comparisons for Kainui and Mildura crops are not of much value, since first crops in these areas were established at wide initial spacings (about 4×4 m and 3×3 m, respectively) and one would not expect the same diameter growth of single trees in the second crop anyway. It is perhaps more relevant and interesting to note from the regressions in Table 4 and from Fig. 2 that all the second crops at Kainui and plot 18 at Mildura are growing faster in basal area than those on upper slopes in Tasman Forest.

Basal area development on upper and mid-slopes at Waiwhero also show a longer period of initial stagnation in the second crop compared with the first. The basal area curve is linear from age five years onwards in the first crop, but not until about age 11 years in the second. Basal area trends for the two plots in the first crop at Waiwhero differ markedly. Although one plot is only a few metres away uphill from the other, it took eight years longer for the mean of the six largest dominants in the former to attain the same basal area as that in the latter. This is typical of the variation found on the Moutere gravels. At age 20 years the second crop dominants have less than half the basal area of their first crop counterparts at the same age.

Volume in the second crop stagnates initially more in keeping with height than with basal area. In Tasman Forest volume does not really start increasing rapidly until age 11 or 12 years for the second crops, whereas the first crops were moving reasonably fast by age 9 or 10 years. By projecting volumes forward graphically, second crops at Tasman Forest will need 3 years less and 5 years more to grow the same volume in the first crop at age 30 years on lower slopes and upper slopes, respectively. On average and over the whole length of stem, taper is less in the second than in the first crop. This same result can be demonstrated by comparing the combined variable stand volume lines for the two crops as shown in Table 5. The slope of the line is greater in the second crop than in the first crop regression, which indicates that there is a higher mean form factor in second crops. The volume figure referred to is a total volume inside bark, the distribution of which will be different in the second crop compared with the first. Volume for volume, the second crop may well be less valuable as the bottom logs will tend to be smaller and the upper logs bigger than their counterparts in the first rotation.

The use of a form-class volume function is obviously preferable to the 2-dimensional volume table, but even it is not a totally satisfactory predictor in all cases. It would have been preferable to have sectionally measured a small sample in each plot and used a volume/basal area line to compute volumes of the plots. This procedure is to be recommended for future investigations of this kind.

CONCLUSIONS

The main conclusions may be summarized as short answers to each of the questions posed in the introduction.

(1) There is evidence of apparent declines in productivity in some places on Mapua and Rosedale soils in the second rotation.

(2) The magnitude of the decline, when it occurs, is of the order of extending rotations by about 2 years to attain the same height, by about 8 years to attain the same basal area, and by about 5 years to attain the same total stem volume.

(3) Mostly the declines in productivity are transitory, representing longer initial periods of stagnation in second crops compared with the first. Some samples revealed decreases of a more permanent nature, but such cases are far less common.

(4) Declines in productivity, however, do not exist everywhere on these soils and do not occur equally on all sites: greatest reductions occur on ridges and upper slopes, particularly secondary ridges; there is less of a reduction as one proceeds down the slope and on the lower slopes and valley bottoms growth in height, basal area and volume is often better in the second crop.

This mensurational evidence appears to substantiate opinions that remedial measures, if any need be taken, would be best directed at shortening the period of stagnation in growth at the beginning of the rotation and on preventing sheet erosion of topsoil on ridges and upper slopes.

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