A GROWTH STUDY IN AN AERIALLY-TOPDRESSED PINUS RADIATA STAND AT RIVERHEAD FOREST

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SYNOPSIS

A Pinus radiata *stand planted in 1927 on phosphate-deficient soil at Riverhead Forest was aerially-topdressed with 5 cwt/acre of superphosphate in 1955. The growth of trees in this stand was investigated in 1965.*

The trees had grown very slowly after planting. The dressing of superphosphate increased height, diameter and volume remarkably. Larger trees responded more quickly than the smaller trees.

Volume increment has not declined since topdressing. Height increment has now started to decline; phosphate and nitrogen foliar concentrations are below the level considered necessary for adequate growth; the crowns show some deterioration. A gradual reduction of volume increment may therefore be expected, although it may not begin for a few years.

INTRODUCTION

Aerial-topdressing is now an accepted forest management practice on the phosphate-deficient soils of North Auckland. The purpose of this study was to characterize the growth of trees in a low site-quality stand before and after topdressing.

Background

The kauri "gumlands" of North Auckland are well known for their low nutrient status. Riverhead Forest, 20 miles north of Auckland, was planted between 1927 and 1933 on some of the poorest of these soils. It is not surprising, therefore, that for many years they were considered the least thrifty stands in New Zealand.

In the early 1950s, fertilizer trials indicated that the trees were stimulated by the application of superphosphate (Weston, 1956, 1958). It was obvious that phosphate would have to be spread over large areas of forest, so, in 1955, experimental aerial-topdressing was attempted (Conway, 1962). In one of these trials superphosphate was applied at three rates, 5, 10 and 20 cwt per acre.

In 1960, D. St. John studied the response by using increment borings. His results were reported by Conway (1962). It was demonstrated that immediately prior to 1955 the basal area increment was declining abnormally, and that the fertilizer reversed this trend. The degree of response was related to the application rate. It was also noticed that the upsurge of growth came two or three years after topdressing and this was considered to be the time necessary for the crowns to be rebuilt.

The present study was confined to the area topdressed at 5 cwt per acre, the rate that has been used almost exclusively in management. The study was done in the winter of 1965, ten years after

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topdressing, when the writer was on the staff of Auckland Conservancy.

The 5 cwt per acre strip lies on the northern edge of compartment 8, immediately to the south of and below Riverhead Forest lookout. The topdressed area covers a wide range of site but this investigation was limited to those areas where the stands were type-mapped as having a volume between 1,000 and 3,500 cu. ft per acre at age 30 to 35. The study area was planted at 8 × 8 ft spacing in 1927 and had no subsequent silvicultural treatment. The following growth data from an Auckland Conservancy plot are typical of the stand studied:

Topdressed in 1955	*Measured in Winter 1965*
Stems per acre	410
Mean top height	65 ft
Mean top d.b.h.o.b.	12.8 in.
B.a. per acre	172 sq. ft
Vol. to 3 in. top, per acre	2,960 cu. ft
M.a.i. 1960–65)	285 cu. ft

Weston (1956, 1958) gives an excellent description of Riverhead Forest locality data, soils, and the history and condition of the forest prior to topdressing.

The soil type of the area discussed here is Parau clay, a brown, granular clay derived from andesitic tuffs under the influence of kauri forest. It is of low nutrient status.

METHOD

The growth data were obtained from the stem analysis of non-malformed trees. To ensure a range of tree sizes, sample trees were selected in the 9, 12, 15 and 18 in. d.b.h. classes.

The stem analysis procedure was adapted from that described by Duff (1960) for obtaining the volumes of trees by sectional measurements. For trees up to 55 ft high, under-bark diameters were taken at the butt, 2.5 ft. 5 ft and at subsequent 5 ft intervals above ground. Where the total height was more than 55 ft, the measurements were made at 10 ft intervals after 10 ft above ground.

In this study, the volume for every year prior to 1965 was based on ring width measurements. All diameter measurements were made to the nearest 0.05 in. and heights to the nearest 0.5 ft. Longitudinal section drawings were used to eliminate gross errors and to determine the total height of the trees prior to 1965.

The results presented here are based on data from 15 trees which were planted in 1927 and which had undoubtedly received fertilizer (see discussion). One of these trees was much shorter for its diameter than the others in its class. It was included in the regression analysis but has been excluded from the graphs and Tables 1 and 3.

Two other trees were felled from an area which had apparently been missed during topdressing. Such areas were common and could easily be demarcated on the ground.

RESULTS

The pattern of growth is illustrated in Figs. 1 and 2 and Table 1. In Fig. 1 the mean height of each of the selected diameter classes is plotted against time; Fig. 2 shows harmonized volume curves. The portion of the curves illustrating the trees in their early years was difficult to harmonize. Presumably the trees had not differentiated into their final size grouping.

(1) *Growth before Topdressing*

Growth immediately after planting was slow, a pattern which is at present being repeated on other comparable sites in the forest. The trees on these difficult sites take about three years to reach two feet in height. Even when established, the trees had slow growth rates for radiata pine. Between 1935 and 1940 (age 8 to 13) the average height growth was 2.7 ft a year, and the average diameter growth was 0.37 in. a year.

The trees did not maintain even those rates of growth indefinitely. It was found, as Conway (1962) had reported, that the annual growth rings gradually narrowed. In the last few years before topdressing the rings were often as little at 0.05 in. apart. Changes in height extension were similar, the decline being evident from about age 20 onward. The decline in height and diameter increment was eventually reflected by an attenuation of volume increment. By 1950 the stand must have been stagnant, and, judging by the

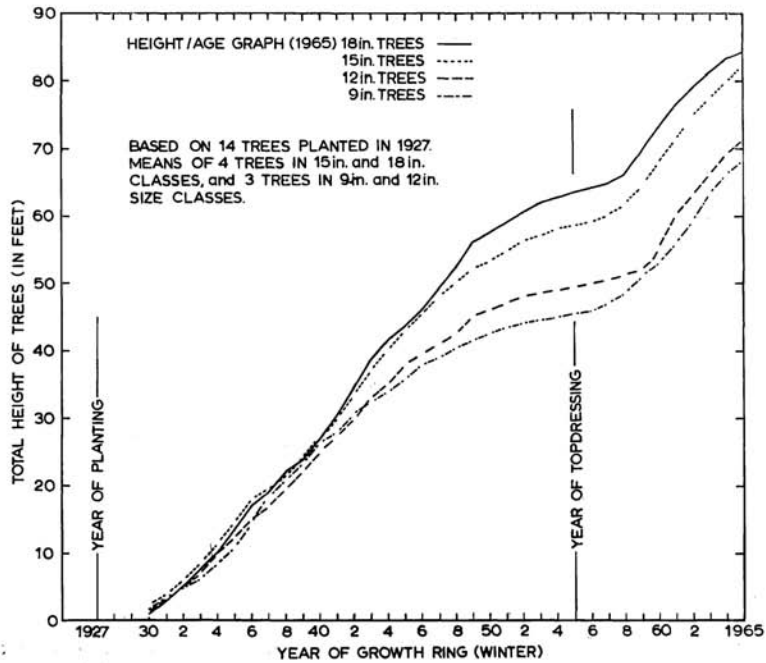

FIG. 1: *Height growth with age.*

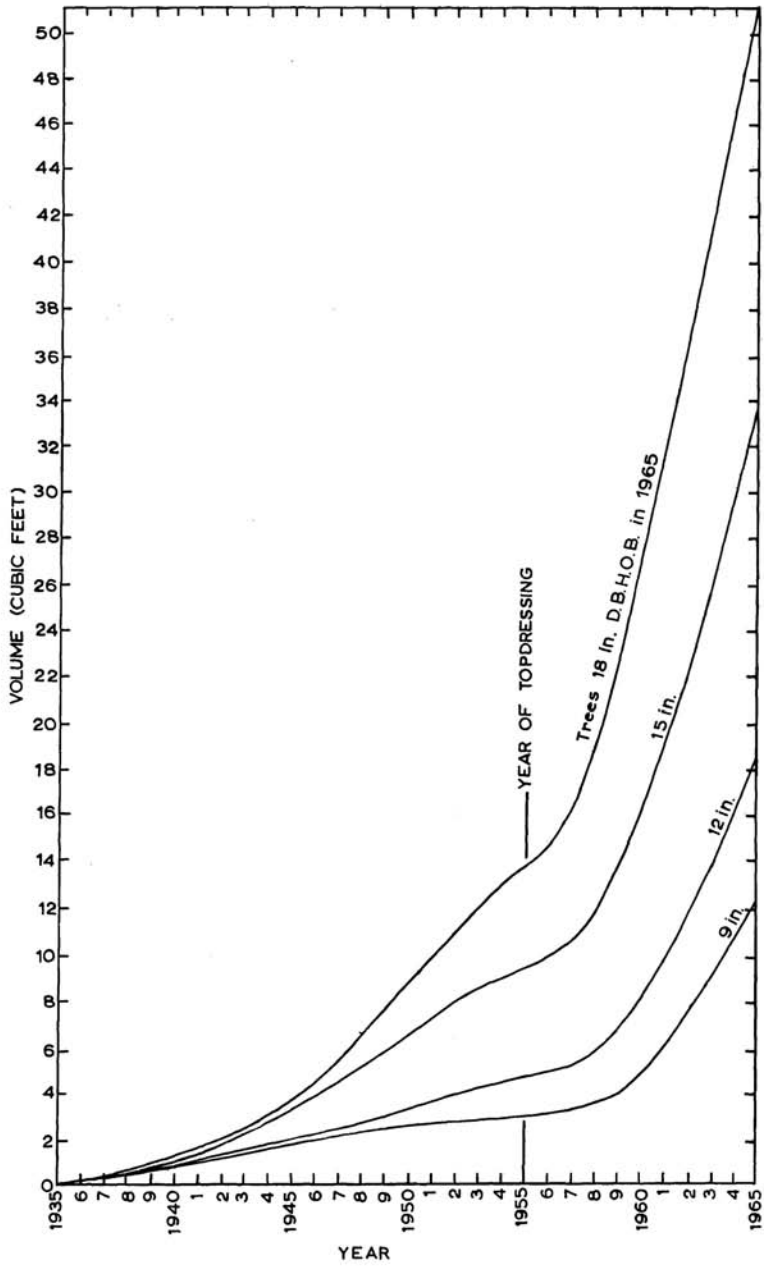

FIG. 2: *Harmonized volume curves for different tree sizes. These curves illustrate the pattern of growth since planting and the response to fertilization.*

amount of malformation currently present, leader die-back was also common. Two trees felled from a non-fertilized area indicated that, without fertilizer, growth would have remained stagnant.

(2) *Growth since Topdressing*

The superphosphate greatly stimulated growth of the trees. This is well illustrated by Table 1 and Figs. 1 and 2. The larger trees responded more quickly than the smaller trees.

The post-topdressing growth data were subjected to regression analysis to determine the relationship of volume at any year after topdressing (v) to the 1955 inside bark diameter (d) and height (h) of the trees and the number of years after topdressing (v). All combinations of d^2h, y, y^2 and dy^2 were examined and the appropriate relationship was found to be:

$$v = 1.9228 + 0.003979d^2h - 0.1107y^2 + 0.04957dy^2$$

This equation accounted for 93.1% of the total variation in v.

There was no further significant reduction in the residual variation by including y. The coefficients of determination (r^2) of the models are given below:

Regression	r^2	*Significance of Additional Variable*
dy^2	0.624	***
$d^2h + dy^2$	0.926	***
$d^2h + dy^2 + y^2$	0.931	***
$d^2h + dy^2 + y^2 + y$	0.932	N.S.

It is significant that none of the topdressed trees shows any reduction in volume increment. In contrast, all but two trees have decreased in height growth in the last few years. Height increment reached an average maximum of about 3.5 ft per annum but began to decline in 1962 or 1963 (7 or 8 years after topdressing). At the stage of maximum height growth a few trees grew more than 5 ft per annum.

(3) *Bark Thickness*

Pinus radiata trees growing on the poor sites at Riverhead have a very much thicker bark than those of the same d.b.h. elsewhere. In Table 2 the breast-height bark thickness of these topdressed trees, together with that for six other trees from the same area, is compared with those given in the Auckland Conservancy taper tables (Duff and Burstall, 1955). They confirm an unpublished study made in 1964 in which 200 trees were felled to produce a local volume table for Riverhead.

(4) *Needle Analyses*

Samples of the previous growing season's needles taken from the trees in the winter of 1965 were analysed and the results are shown in Table 3.

TABLE 1: SUMMARY OF GROWTH DATA — *PINUS RADIATA*, PLANTED 1927, TOPDRESSED 1955

Diam. Class 1965 (in.)	*No. of Trees*	*Mean Vol. (cu. ft)*		*P.M.A.I. (cu. ft)*					*Season Began after Topdressing*	*Response Topdressing*
				Before Topdressing			*After Topdressing*			
		1955	*1965*	*1935–45*	*1945–50*	*1950–55*	*1955–60*	*1960–65*	*Height*	*Volume*
9	3	3.14	12.72	0.16	0.16	0.09	0.36	1.51	1957–58*	1958–59
12	3	4.79	18.83	0.18	0.27	0.28	0.67	2.09	1959–60	1957–58
15	4	9.52	33.93	0.31	0.64	0.58	1.38	3.46	1957–58	1957–58
18	4	13.55	49.85	0.35	1.00	1.00	2.67	4.78	1957–58	1956–57

* One tree was exceptional as its height growth improved in 1955–56. This has influenced this figure.

TABLE 2: COMPARISON OF BARK THICKNESS AT BREAST HEIGHT

Diam. Class (O.b.) (1965) (in.)	*No. of Trees*	*Bark Thickness at B.h. According to 1952 Taper Table (in.)*	*Average Measured Bark Thickness at b.h. (in.)*	*Difference (in.)*
9	5	0.50	0.80	0.30
12	6	0.65	1.02	0.37
15	5	0.80	1.25	0.45
18	5	1.05	1.45	0.40

TABLE 3: FOLIAR ANALYSES

	No. of Trees	*% Dry Weight*				
		N	*P*	*K*	*Mg*	*Ca*
Fertilized trees	15	1.38	0.093	0.72	0.16	0.30
Unfertilized trees	2	1.31	0.051	0.53	0.12	0.14

In both the fertilized and unfertilized trees, the average phosphate concentration is below the 0.11% level considered normal for a completely healthy stand (Will, 1965). Of the 15 fertilized trees only two were above this level and two were very low (0.065% and 0.055%).

Nitrogen is at the critical level (1.4%). The other minerals are adequate (Will, 1965).

DISCUSSION

(1) *Uneven Fertilizer Spread*

One feature of the aerially-topdressed area was that there were many patches where no response had occurred. Without doubt this was caused by uneven fertilizer spread. In the present study it was decided that the growth of only those trees that had obviously received fertilizer should be studied in detail; however, two trees were felled from near the centre of one of these missed areas, and their growth since 1955 showed no alteration of past trends.

For forest fertilization, unlike agriculture, it is neither necessary nor economic to fertilize annually. In this study, trees which received a dressing of fertilizer showed large responses which have been maintained for at least 10 years. In such circumstances, uneven fertilizer spread produces a very variable stand in which the potential of topdressing is not realized. It is therefore important that fertilizer should be spread as uniformly as possible. It may be worth paying a premium to obtain this even spread.

(2) *Comparison with Fertilizer Trials*

It is interesting to compare the results of this study with those of hand-topdressed plots in Riverhead. The comparison is complicated by the type of fertilizer distribution pattern. In aerial-topdressing, it is impossible to know the exact amount of fertilizer any small area has received; with hand-topdressing this is known accurately. Riverhead hand-topdressed plots are normally small (1/10 acre) and without treated surrounds. Edge effects on such plots can be important.

One series of hand-topdressed plots (A160) in Riverhead Forest was laid out in 1955 on a site similar to those investigated in this study (Weston, 1958). These plots are in the same compartment as the aerially-topdressed strips and they were also planted at 8 × 8 ft spacing in 1927. The phosphate treatments were 2, 4 and 20 cwt per acre of superphosphate. Nitrogen and zinc were also tried singly and in combination with phosphate, but without success. The main measurements recorded were diameter at breast height and crown density index.

The 4 cwt and 20 cwt plots in this hand-topdressing trial have not shown an attenuation of basal area increment since 1955 (Weston, pers. comm.). In 1965 the foliar concentrations of phosphate in the 4 cwt plots were 0.08%. Apparently the 4 cwt plots have for many years had a phosphate level below that considered critical, the fertilizer giving an adequate supply for two years only (Will, 1965). The foliage density of the 4 cwt plots increased markedly after topdressing, but after 1958 began to decline again (Weston, pers. comm.). Thus, the basal area trend of the hand-topdressed plot does not conflict with the growth response noted in the trees from the aerially-topdressed strip. The foliar levels are also comparable. Furthermore, in 1965 the trees felled in the aerially-topdressed area had a similar density of foliage to those in the 4 cwt per acre hand-topdressed plots.

(3) *Growth Trends*

It is apparent from the early records (see Weston, 1956, 1958) that the crowns of the trees on the less fertile sites began to deteriorate soon after canopy closure. In this study, a noticeable decline of height extension was recorded from about age 20 onwards, and it is reasonable to assume it was due to a deterioration of the crowns.

After topdressing it took time for the crowns to rebuild and hence for growth to improve. At the same time the root systems would have been invigorated and would be tapping a larger volume of soil. Will's and Weston's records on the foliage and crowns of the 4 cwt per acre hand-topdressed plots suggest that the nutrient cycle reaching an equilibrium 3 to 5 years after topdressing. Since then there has been a gradual drop in crown density and foliar potash concentrations have remained static, at about the same level as the controls. These observations indicate that available phosphate is again becoming inadequate for tree growth.

The height increment of the trees sampled from the aerially-topdressed strip showed a decline 7 or 8 years after topdressing.

Although this also indicates a shortage of phosphorus, the possibility that this decline is an expression of age or exposure cannot be ruled out.

It is likely that a decline in volume increment will gradually become apparent within the next few years. The larger trees, for instance, have had a steady volume increment for some time. Furthermore, competition between trees is becoming a factor which must be considered; its effect will be to decrease diameter and volume increments of individual trees. Before topdressing, and for several years after the topdressing, competition was not important as the trees were extremely unthrifty to the extent that mortality occurred in untreated areas (see Weston, 1958).

CONCLUSIONS

The following pattern of growth was indicated from this stem analysis study of an aerial-topdressed radiata stand at Riverhead Forest:

(1) The initial growth after planting was slow, the trees taking about 3 years to reach 2 ft in height.

(2) At no stage before topdressing could growth be described as very good. At the time of topdressing, the trees' growth had begun to decline.

(3) After topdressing in November 1955, the larger trees responded the following growing season, although they did not reach maximum rates of growth until 1959. The smaller-sized trees, presumably because of the greater deterioration of the crowns, responded two or three years after topdressing.

(4) Volume and height growth after topdressing were very much greater than at any time prior to topdressing.

(5) No decline in volume increment was apparent up to 10 years after topdressing. Height growth began to fall off seven or eight years after topdressing.

(6) Needle samples from the trees studied indicate that there is currently a deficiency in phosphate and possibly nitrogen. Crowns are also beginning to deteriorate. A gradual reduction of volume increment may begin in a few years' time.

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