

Fertilizing radiata pine plantations: predicting long-term effects

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ABSTRACT

Are the gains achieved by forest fertilization short-lived or sustained until harvest? Insight into this question is provided using a radiata pine growth model modified to include the growth and yield effect(s) of fertilizer in Golden Downs Forest to simulate a tending schedule for the production of structural sawlogs or for log export. Simulations showed that gains induced by fertilization remain present at age 25 and later, suggesting that fertilizer, rather than inducing a temporary growth spurt only, provides an advantage to a forest which is maintained over much of its life.

For resource managers worldwide, forest fertilization is becoming an increasingly common silvicultural practice to increase the quantity of wood produced. This is true of exotic forests in New Zealand where fast-growing, fertilizer-responsive radiata pine (*Pinus radiata* D. Don) is grown in planted stands using relatively short rotation lengths (25 to 30 years). The short-term (five to seven years) effects of fertilization on radiata pine have been documented numerous times (Mead and Gadgil 1968, Woollons and Will 1975, Hunter and Skinner 1986), and there is also some information available about fertilizer effects over longer periods (Waring 1980, Turner 1982, Woollons 1985). However, these studies have often been conducted using experimental conditions which deviate considerably from operational forest management practices.

Growth modelling has been recognized as a way which can assist forest managers in evaluating the effects of different silvicultural treatments on the growth and yield of a forest. Lowell (1986a) recently modified an existing growth model to allow the long-term effect(s) of fertilizer to be predicted for Golden Downs Forest. The purpose of this paper is to use the model to present the probable outcomes of forest fertilization on a stand of radiata pine which has been thinned and fertilized using a tending regime for the production of structural sawlogs or for log export.

THE MODEL AND MODIFICATIONS

For a more detailed discussion of each component described in the following section – including accuracy and precision of each – the reader is referred to the literature cited in each section.

Original Growth Model

The growth model which was modified to include fertilizer effects was developed for Golden Downs Forest – a 30,000 ha exotic plantation forest in the Nelson region which is owned and managed by the New Zealand Forest Service. Briefly, the growth functions of the model – a set of related differential equations – use a 'state-space' approach where the state of the system (i.e. the forest stand) is defined at any point in time by basal area, top height, and stocking. The path along which each of these state variables moves over time is determined by

site index and the present state of the forest stand. Stocking and basal area are projected as a function of all three state variables, but height growth is a function of top height alone. Stand treatments such as thinning which alter the stocking and/or basal area of the stand simply redefine the 'state' of the 'system'. A more detailed discussion of this model is presented in Garcia (1979) and Garcia (1984). A detailed evaluation of the accuracy and precision of model estimates is also documented in Lowell (1984).

Fertilizer Effect: Growth

Using data from five fertilizer trials established in Golden Downs Forest from 1969 to 1978, the growth functions of the original model were modified to include fertilizer effect. These trials were established in stands of radiata pine which varied in age (6-14 years), site quality (23-31 m base age 20), stocking (190-1481 stems per ha), and basal area (2.5-23.4 m² ha⁻¹) to which were applied elemental nitrogen (0-300 kg ha⁻¹) and/or phosphorus (0-240 kg ha⁻¹). In these trials, fertilizer was shown to cause a basal area response, but neither top height nor stocking was affected. Consequently, the fertilizer modification to the original model was developed such that only basal area responds to fertilization. The modification consists of three sub-models: 1) time elapsed since fertilizer application, 2) rates of fertilizer application, and 3) stand characteristics at the time of fertilization. These sub-models indicated that 1) fertilizer affects basal growth only for the four years following application with the greatest effect occurring in the first two years, 2) phosphorous alone will cause no basal area response whereas nitrogen alone, or nitrogen and phosphorous combined will affect basal area growth and, 3) at the time of fertilization: a) increasing basal area in a stand results in an increasing growth response, b) younger stands respond to fertilizer more than older stands, and c) a stand on a poor site responds to fertilizer more than one on a good site. A more detailed discussion of the modification and the three sub-models is presented in Lowell (1986a) and Lowell (1984).

Fertilizer Effect: Volume

A volume system was developed specifically for the modified model to account for the shape change that occurs in trees after a stand has been fertilized (Pegg 1966, Miller and Cooper 1973, Mitchell and Kellogg 1972). Within this system, parameters of the diameter distribution are estimated from stand stocking and basal area. A cumulative Weibull function is then used to generate an estimated dbh distribution by one-cm classes and the height of the mean tree in each one-cm class is estimated using the tree height equation. A taper equation is then integrated for total volume and volumes to specified heights and/or selected top diameter limits. Volumes for each product are summed over the entire distribution to provide volume estimates of various products for the stand. Details of this methodology are discussed in Lowell (1984), Lowell (1986b), and Lowell (in prep).

METHODS

A forest-tending schedule designed to produce structural sawlogs or for log export in radiata pine plantations was simulated twice. In one simulation, the stand was fertilized at age 12 with 200 kg ha⁻¹ and in the other it was not. In both cases, site index

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was specified at 26 (m base age 20), and simulations were begun at age six with 1000 stems ha^{-1} stocking and 5.0 $\text{m}^2 \text{ha}^{-1}$ basal area. At age seven stands were thinned to waste with a residual stocking of 550 stems ha^{-1} and grown to age 12 where a waste thinning was conducted leaving a residual stocking of 300 stems ha^{-1} . Both the unfertilized and fertilized stands were then grown by the model from age 12 to age 35.

Graphs of results were produced including the volume of chipwood and sawlogs. Sawlog volume was defined as the lowest 6 m of a tree (i.e., the buttlog) plus all volume between a 6 m height and a 25 cm top diameter (inside bark). Chipwood was defined as the volume between the sawlog top (6 m height or 25 cm top diameter) and a 15 cm top diameter (inside bark).

Values for a variety of stand parameters were also tabularized for stand ages of 16 years (the point when fertilizer effects are maximal), 25 years (the target rotation age), and 35 years (the terminal age in this study). The change between the fertilized and unfertilized stand was also calculated for each age and stand parameter.

RESULTS AND DISCUSSION

In general, the gains achieved by fertilization at age 12 remain present at a rotation age of 25 years and also at age 35 to a lesser extent (Figure 1 and Table 1). This is especially evident in Figure 1a (mean stand diameter), 1b (basal area), and 1d (total volume). Interestingly, Figure 1f shows that the volume increase indicated in Figure 1d is entirely sawlog volume while chipwood volume remained nearly equal in the two stands. The annual increment curves in Figure 1c and 1e suggest that the benefits of fertilization are realized early, but after the initial advantage provided by fertilizer, the annual growth rate soon becomes nearly equal for both unfertilized and fertilized stands. However, the four-year growth spurt induced by fertilizer ultimately causes more basal area and volume to accumulate (Figs. 1b and 1d, respectively). Given that tree height has not been affected by the fertilizer, this suggests that the increased volume increment for fertilized stands between ages 12 and 16 is due to increased stand basal area and subsequent tree shape change induced by the fertilization.

Table 1 indicates that, for total volume, the fertilized stand showed an increase of 4% at age 25 compared to the unfertilized stand. Considering that a sawlog tending regime was simulated, however, a better gauge of the effectiveness of fertilizer treatment is the 6% increase in sawlog volume at age 25. Whether a sawlog volume increase of this magnitude at a rotation age of 25 years is acceptable must be decided by individual forest managers concerned with specific forest stand conditions. In making such a decision, it may also be useful for a manager to evaluate scientific evidence that suggests that log quality will change with fertilization due to an increase in branch size; the increased volume may be of inferior quality although the logs themselves will be larger.

Both Figure 1 and Table 1 suggest that the effects of fertilization are less pronounced during the later ages of a stand despite the application of fertilizer to relatively young stands. This suggests that if a forest manager is to reap the full benefits of ferti-

Table 1. Stand parameters at selected ages.

Parameter	Age 16			Age 25			Age 35		
	Unfr	Fert	Chng	Unfr	Fert	Chng	Unfr	Fert	Chng
Mean dbh (cm)	29.5	30.4	+0.9	42.2	42.9	+0.7	52.9	53.4	+0.5
Basal area ($\text{m}^2 \text{ha}^{-1}$)	20.0	21.2	+1.2	38.1	39.2	+1.1	53.5	54.4	+0.9
Total volume ($\text{m}^3 \text{ha}^{-1}$)	115	122	+7	317	329	+12	555	559	+4
Sawlog volume ($\text{m}^3 \text{ha}^{-1}$)	66	71	+5	205	217	+12	452	458	+6

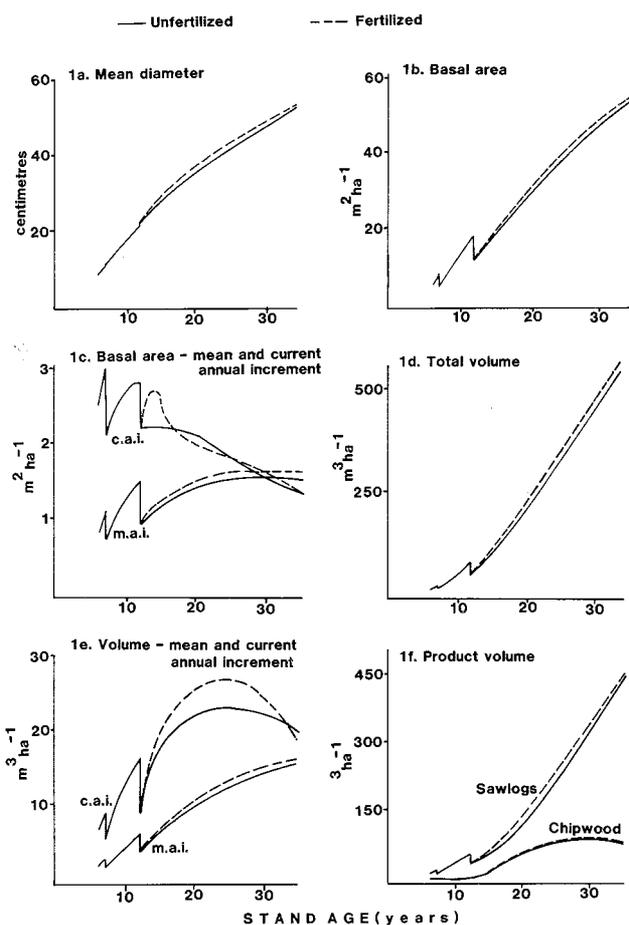


Figure 1. The predicted response to 200 $\text{kg} \text{ha}^{-1} \text{N}$ applied at age 12 to a radiata pine stand of site index 26m.

lization, the treated stand must not be allowed to grow to senescence but must be harvested while it is still fully utilizing available growing space.

However, an alternative conclusion is also reasonable. The fertilizer modification of the original growth model was based on limited data and results that show fertilizer effect to be 'wearing off' after age 25 may be a result of data limitations and model imprecision which is known to decrease with increasing stand age.

As a final point, forest managers must be aware that results presented are based on experimental conditions which are relatively tightly controlled. In an operational setting, fertilizer gains are likely to be reduced. For example, Ballard and Will 1971 showed that using aerially applied fertilizer, the actual rate of fertilization at any point in the stand will vary considerably from the nominal stand rate. This could lead to reduced gains from topdressing with fertilizer, as leaching losses are likely to be higher where very heavy concentrations are applied.

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