# Representing Growth Response to Fertilization in the Prognosis Model for Stand Development

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## ABSTRACT

*Capability to represent effects of fertilization has been added to the Prognosis Model for Stand Development. As implemented in version 6, the extension is calibrated only for applications of 200 lb nitrogen applied in the form of urea. Direct and indirect effects are based on growth 10 years after treatment for diameter effects, and 6 years after treatment for height effects. Mortality is not affected in the model. After 10 years, only indirect effects are represented through the normal dynamics of the Prognosis Model. Control of timing is provided through a keyword, the parameters of which are documented in this note.*

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KEYWORDS: Douglas-fir, grand fir, diameter increment, height increment

A new subroutine that represents response to fertilization has been added to version 6.0 of the Prognosis Model for Stand Development (Stage 1973). At this time, coefficients for growth response relative to no fertilization are based on 91 permanent plots located in northern Idaho. Differences between treatment and no-treatment after a 10-year period are used for the diameter-growth response. Responses in height increment are based on 6-year data.

Although accretion, which is based on the height and diameter increments of individual trees, is obviously an important component of growth, so is mortality. There is, however, no representation of mortality effects directly related to treatment in this model. Available evidence indicates that fertilization also influences mortality rates indirectly by either accelerating stand development through time or by long-term alteration of stand structure. These changes in mortality rates derive from the differential fertilization response across size classes within a stand. The changes in

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stand dynamics continue much longer than the direct response to fertilization. These indirect effects will occur in the normal operation of the mortality submodel of the Prognosis Model (at least in the Inland Empire variant). Whether their magnitude is correct remains to be evaluated.

Although use is limited to nitrogen fertilization at this time, procedures for directing the simulation have been structured to facilitate extending its scope to applications of phosphorus and potassium at varying rates when response results become available.

## CONTROLLING PROGRAM EXECUTION

Simulation of fertilizer effects is invoked by adding one keyword-record to the sequence of Prognosis keywords controlling other management actions in the simulation scenario (Wykoff 1986; Wykoff and others 1982). This keyword contains the characters 'FERTILIZ" in the first eight columns followed by five fields of parameters in columns 11-20, . . ., 51-60:

**FERTILIZ**     field 1:   Year in which fertilization treatment is to be applied; if blank, it will be applied at the start of the projection.

                field 2:   Level of nitrogen to be applied; currently, only treatments with 200 lb/acre can be represented; if blank, 200 lb/acre nitrogen fertilization will be applied.

                field 3:   Level of phosphorus to be applied; currently treatments with phosphorus are not represented. This value will be ignored.

                field 4:   Level of potassium to be applied; currently, treatments with potassium are not represented. This value will be ignored.

                field 5:   Efficiency parameter specific to this fertilization application. This parameter is intended to represent the "fall-down" between results from research plots and the response expected from application at an operational scale. Default = 1.0.

To illustrate the use of this keyword, figure 1 lists a set of keywords for simulating the development of a Douglas-fir plantation on a *Thuja/Clintonia* habitat type. Figure 2 shows three treatments compared to a no-treatment alternative:

    1. Fertilization at age 70 (date = 2060) invoked by adding the FERTILIZ keyword,
    2. Thinning at age 40 (date = 2030) invoked by the THINBBA keyword, and
    3. Both thinning as in 2 followed by fertilization as in 1.

## DATA SOURCE

Version 1.0 of the Fertilization Model is calibrated using experimental treatments of 91 plots clustered at 13 locations in northern Idaho. These locations include **Abies grandis/Pachistima myrsinites** and **Thuja pticata/Pachistima myrsinites** (Daubenmire and Daubenmire 1968) habitat types. Two conifer species are represented: Douglas-fir **(Pseudotsuga menziesii)** and grand fir **(Abies grandis).** The model quantifies the change produced by nitrogen fertilization (200 lb of actual N in 440 lb of urea per acre) on diameter and height growth of individual trees. Observations spanned a period of 14 years after treatment.

The model is based on Shafii's (1988) analyses of these and several related sets of data. The latter data sets were used for evaluation of model behavior.

Use of the current version of the fertilization model is most defensible under conditions similar to those outlined above. The computer program, however, is designed to simplify revision when new fertilization results are available. Whenever data are outside the range of the calibration data, warning messages are printed advising that results should be used with caution. Nevertheless, the model continues processing the data, assuming valid application.

| Reference line | Keyword record | | | | | | |
|---|---|---|---|---|---|---|---|
| | Keyword | Field 1 | Field 2 | Field 3 | Field 4 | Field 5 | Field 6 | Field 7 |
| 1 | NOTREES | | | | | | |
| 2 | NUMCYCLE | 15 | | | | | |
| 3 | RANNSEED | 3493. | | | | | |
| 4 | INVYEAR | 1990 | | | | | |
| 5 | NOTREES | | | | | | |
| 6 | FERTEST | | | | | | |
| 7 | ESTAB | 1990 | | | | | |
| 8 | PLANT | 1993 | 3. | 600. | | | |
| 9 | END | | | | | | |
| 10 | MGMTID | | | | | | |
| 11 | F&TH | | | | | | |
| 12 | SPECPREF | 2030. | 3. | -2. | | | |
| 13 | THINBBA | 2030. | 60. | .9 | | | |
| 14 | FERTILIZ | 2060. | | | | | |
| 15 | STDINFO | 116.0 | 530.0 | | 45.0 | 10.0 | 33.0 | |
| 16 | PROCESS | | | | | | |
| 17 | STOP | | | | | | |

Line 1:   Projection starts with "bare ground."

Line 2:   Run Projection for 15 cycles.

Line 3:   Initializes random number generator.

Line 4:   Date for start is 1990.

Line 5:   Indicates next record is a label for the stand.

Line 6:   FERTEST is the label for this stand.

Line 7:   Invokes Regeneration Component and signals keywords to follow are interpreted by that component.

Line 8:   Plant in year 1993 with Douglas-fir at 600 trees/acre.

Line 9:   Terminates Regeneration Component packet of keywords.

Line 10: Indicates next record is a label for the management scenario being simulated.

Line 11: F&TH is the label for management.

Line 12: Favor Douglas-fir in partial harvests in and after year 2000.

Line 13: Thin from below to residual basal area of 60 ft$^2$ per acre, removing 90 percent of trees represented by each tree record. (Omit this keyword if no thinning is being simulated.)

Line 14: Apply 200 lb nitrogen (default) in year 2060. (Omit this keyword if no fertilization is being simulated.)

Line 15: Specifies site attributes:  Forest is habitat type THPL/CLUN, age = 0, aspect = NE, slope = 10 percent, elevation = 3,300 ft.

Line 16: Starts projection.

**Figure 1—**Keywords used to generate the curves in figure 2 by omitting FERTILIZ (line 14) and/or THINBBA (line 13) as appropriate.
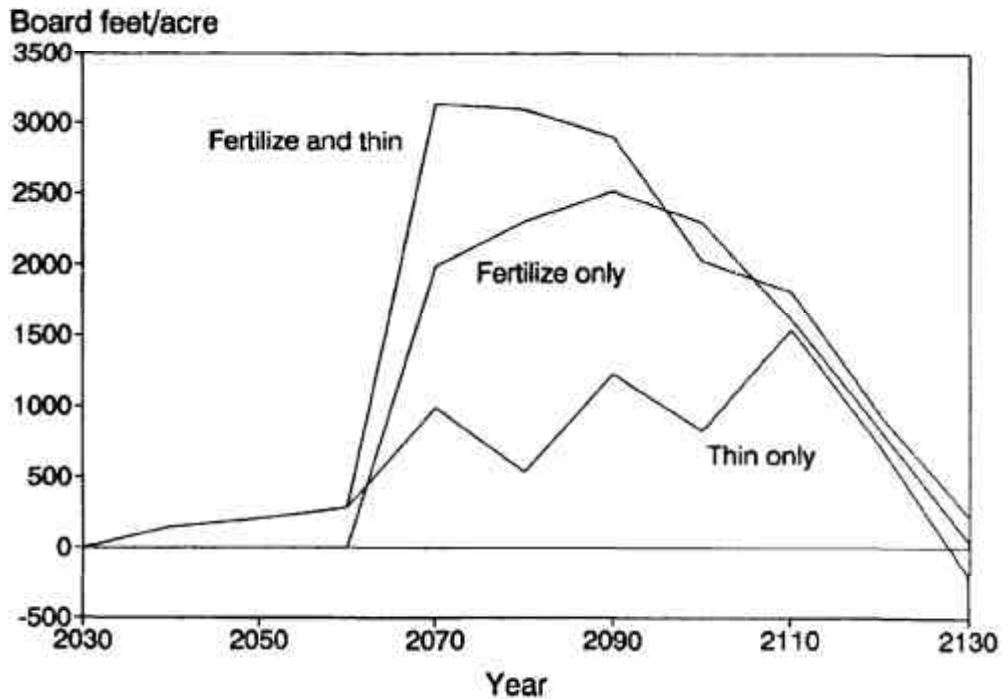
**Figure 2**—Differences between treatment and control for three treatments.

## HOW THE MODEL WORKS

Response to fertilization is composed of two effects: direct and indirect. Direct effects include changes in physiological efficiency that produce changes in the physical structure of the tree-needle length, crown development, and increased radial and height increment. In addition, there are indirect effects because growth is a deviation-amplifying process. A bigger tree can produce more growth than a smaller tree of the same physiological efficiency. And because tree sizes have been changed, internal stand dynamics also alter the competitive status of the individual trees. In models such as the Prognosis Model, which are built according to growth architecture rather than yield architecture (Farnham and others 1986), indirect effects are represented by the basic model once the direct effects have subsided.

**Response in Diameter Growth**

The diameter response model is based on Shafii's (1988) analyses of responses, with some reanalysis to take advantage of improvements in the formulation of the Prognosis diameter growth function (Wykoff in press). Of the several response periods reported by Shafii and others (in press), the 10-year period was selected because although direct effects seemed to have subsided by about 6 to 8 years after treatment, indirect effects would not be represented by the main Prognosis Model until the end of the projection cycle, which is normally 10 years. Shafii modified the basic Prognosis Model equation for individual tree basal area growth (Wykoff 1986) to introduce a treatment effect on values of the coefficients in the equation. The basic model is linear in the coefficients with a logarithmic transformation of the dependent variable. Therefore, the logarithm of the response ratio CR> for basal area growth is the difference between the expression for untreated trees and the expression with coefficients modified by the treatment effect. Variables in the expression that do not interact with treatment sum to zero in the difference and need not be considered. Remaining variables that interact with the fertilization treatment are tree diameter and overstory competition.

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Table 1—Effect of tree diameter and stand basal area on response to 200 lb/acre nitrogen fertilization (ratio response of basal area increment per tree)

| D.b.h. | Basal area larger trees | |
|---|---|---|
| | 50 ft$^2$ | 150ft$^2$ |
| Inches | | |
| 6 | 1.32 | 1.54 |
| 10 | 1.37 | 1.56 |

The resulting equation is:

$$\ln(R) = 0.1108 \ln(DBH) + 0.003004\ BAL/\ln(DBH+l)$$

where:

$DBH$ = breast high diameter (inches)

$BAL$ = basal area in trees larger than the subject tree (ft²).

Hence, the relative response is greater in dense stands than in more open stands (table 1 and figure 3). These coefficients suggest that dominant trees are better competitors for the nitrogen naturally available in the site and that nitrogen is more limiting in denser stands. Note, however, that direction of the response depends on the scale of measurement. Whereas these results are reported on a relative scale (percent response), Shafii showed that absolute growth responses on a scale of basal area increment were in just the opposite direction.

The derivation of the diameter response ratio was based on an equation roughly similar to that used in the Prognosis Model for trees larger than 5 inches d.b.h. In the fertilization subroutine, however, the same equation for relative response is applied to trees less than 5 inches as well, but with a maximum response ratio of 2.68, which is the value for a 3-inch tree with 400 ft² of competition in larger trees. This truncation generates the small, flat triangular plateau in the upper right of figure 3.
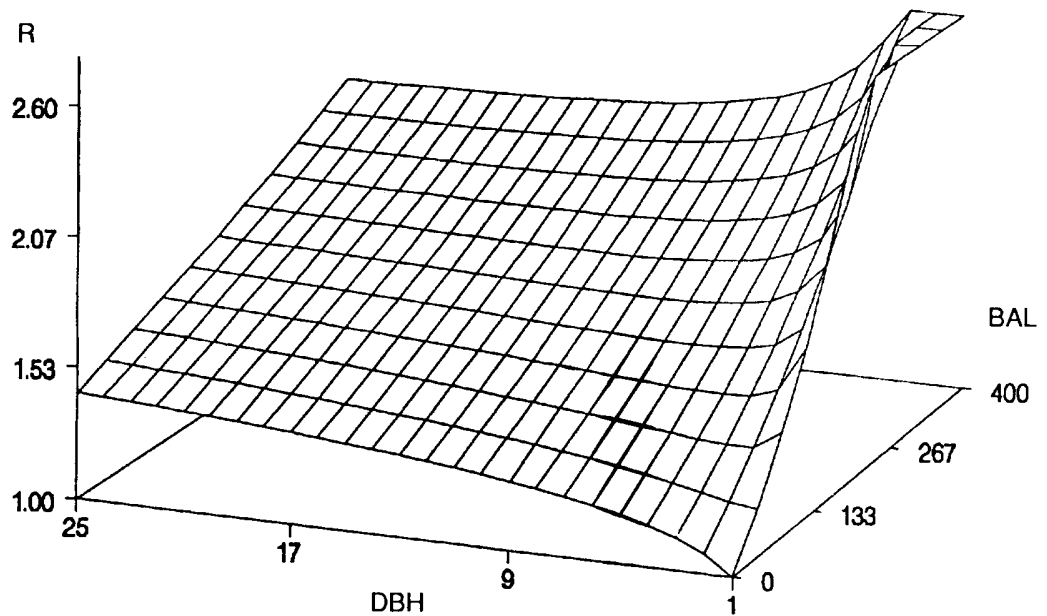


Figure 3—Response ratio for basal area increment depends on tree diameter and basal area in trees larger than the subject tree.

**Response in Height Growth**

Although diameter increment data were available for 10 years after treatment, the height measurements covered only 6 years. The ratio of height increment (feet) of fertilized trees to increment of the nonfertilized trees was 8.58/7.38 = 1.163 or a 16 percent response. Because other stand attributes did not affect the percentage height response, the simple ratio suffices.

**Duration of Response**

Shafii's analyses of gross and net basal area response of the total stand showed that response peaked at about 6 years. Starting between 8 and 10 years, there was no further response to the end of the ll-year study. Unfortunately, measurement error of diameter increment for short time intervals is so large in comparison to the treatment response that analysis of the yearly distribution of response at the individual tree level did not appear fruitful. Therefore, we chose to calculate the total response for 10 years. Fortunately, the 10-year duration of response coincides with the length of the projection cycles most commonly used when running the Prognosis Model. If the projection cycles are less than 10 years, however, or if the fertilization activity is scheduled for less than 10 years before the next cycle boundary, then the results will be somewhat biased relative to the data used for calibration.

The model applies the calculated ratio to the mean annual change in diameter-squared for a period of 10 years or for the length of the current projection cycle, whichever is shorter. If the current cycle is less than 10 years, the remaining years of fertilizer effect are carried to the next cycle. For that additional period, a new value of the ratio is calculated using the updated tree diameter and stand basal area. Hence, there will be a small additional indirect effect in the second (and any subsequent) periods within the 10 years of response.

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